Man-made Shooting Stars
Aerothermodynamics and Flight Data on-Demand

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(2): Nihon University, College of Science and Technology

Outline

1. ALE's Mission
2. ALE's Technologies
3. Research Challenges
4. Shooting star Ablation
5. Shooting star wake Aerodynamics
6. Shooting star Brightness
7. ALE's project news
8. Conclusions
9. Contributions to the community

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Pr. H. Sahara and his students (Tokyo Metropolitan University, Hino campus)
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My former colleagues at Ecole Centrale-Supelec, NASA Ames and JAXA CAC

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ALE at Glance

- ✓ Founded by Dr. Lena Okajima in 2011
- ✓ 20 members from Space Engineering, Business and Lobby backgrounds
- ✓ Collaboration with JAXA and Japanese universities

- ■ Vision: Anchor Space in our Culture to Propel Mankind to new endeavors
- ■ Mission: Bring Space closer.
- ■ Values: Curiosity, Pioneer, Evolution

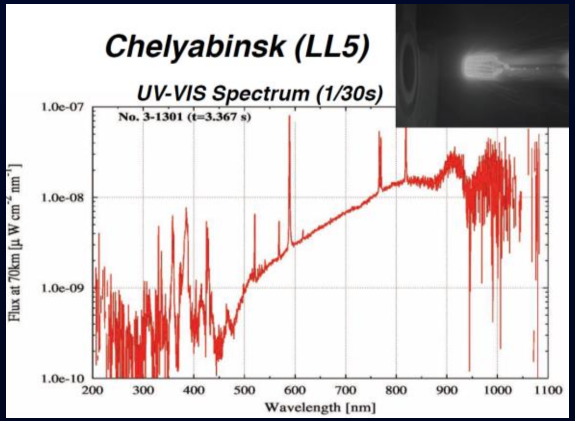
Background:
Space policies and businesses have been essential in enhancing our daily life thanks to observation, telecommunication, navigation services
However, only of few of us is knowledgeable in space business as the use of space has not been maximized yet.

At ALE:
We aim to take on the challenges posed by an increasingly competitive industry and an ultra connected society. Our game changing approach enables us envision to anchor space in our culture to propel man-kind to new endeavors. We will expand our horizons, bridge multi disciplinary fields and transcend space to a new dimension by putting emphasis on art, entertainment and culture.

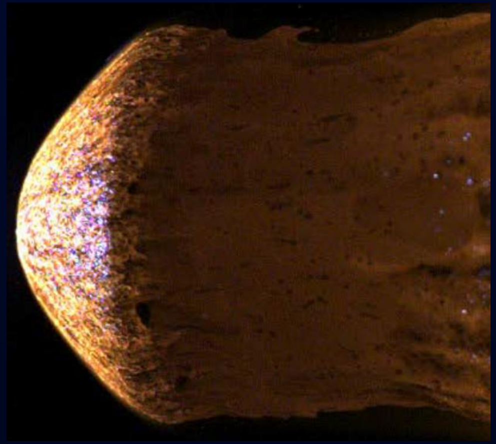
From natural meteors…

- **Hypersonic Meteors conference (Colonna et al., 2017)**
- **Experiments**

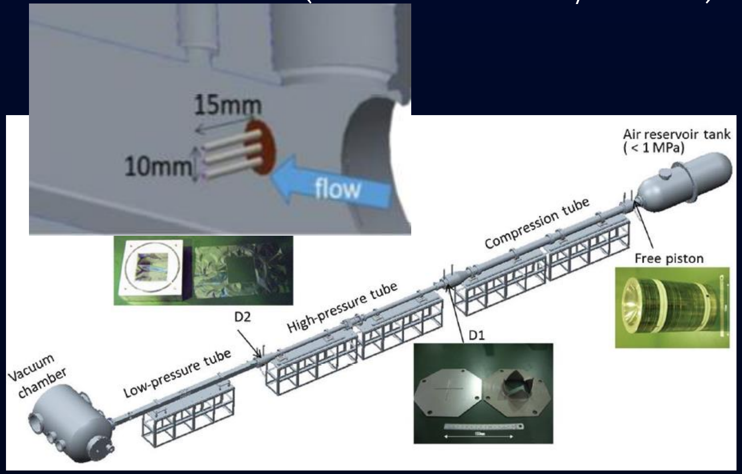
JAXA & Nihon Univ. (Abe et al., 2018)

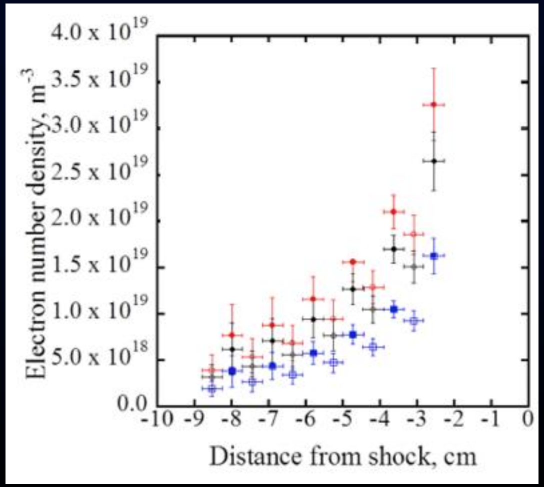


NASA Ames (Stern et al., 2018)

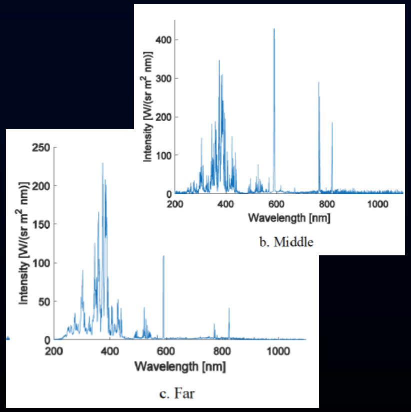


JAXA & ALE (Lemal et al., 2018)

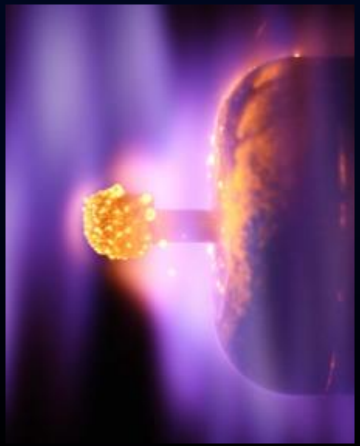




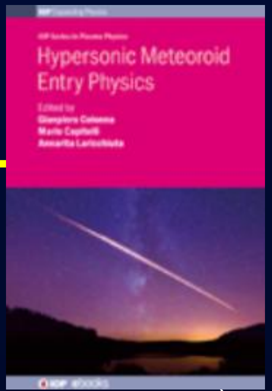
VKI (Magin et al., 2018)



IRS (Loehle et al., 2018)

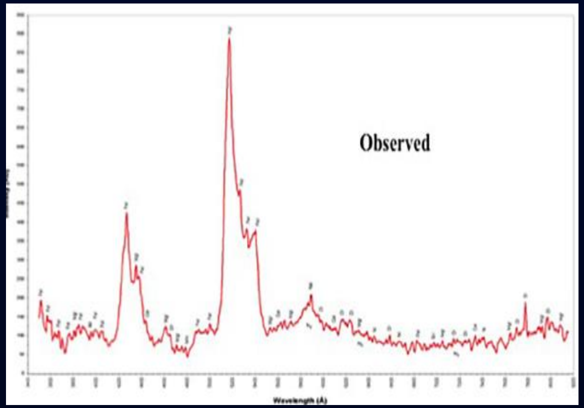


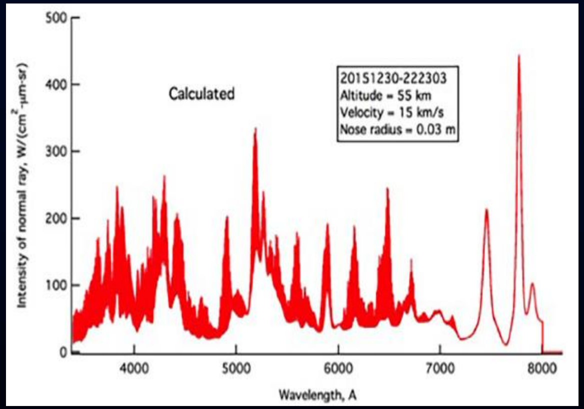
From natural meteors…



- Hypersonic Meteors conference (Colonna et al., 2017)
- Computations

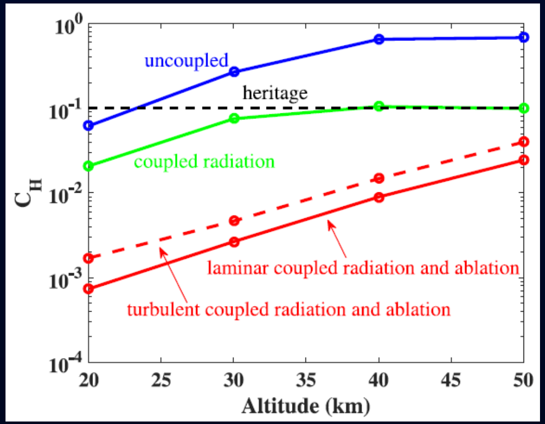
KAIST (Park et al., 2015)

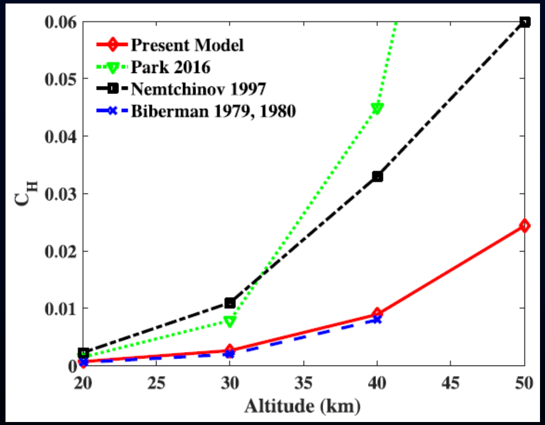




Small meteors

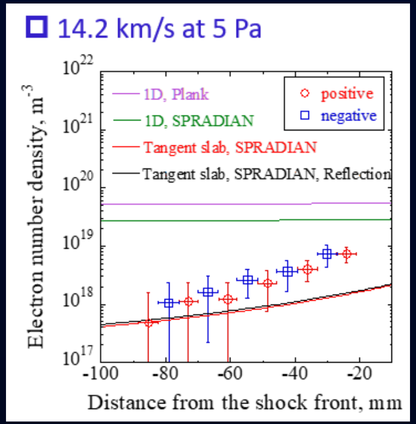
NASA Langley (Johnston et al., 2018)

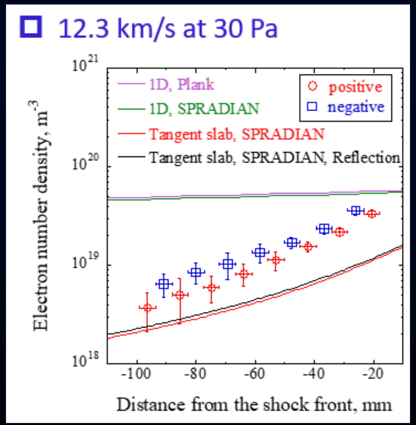




Large meteors

JAXA & ALE (Lemal et al., 2018)

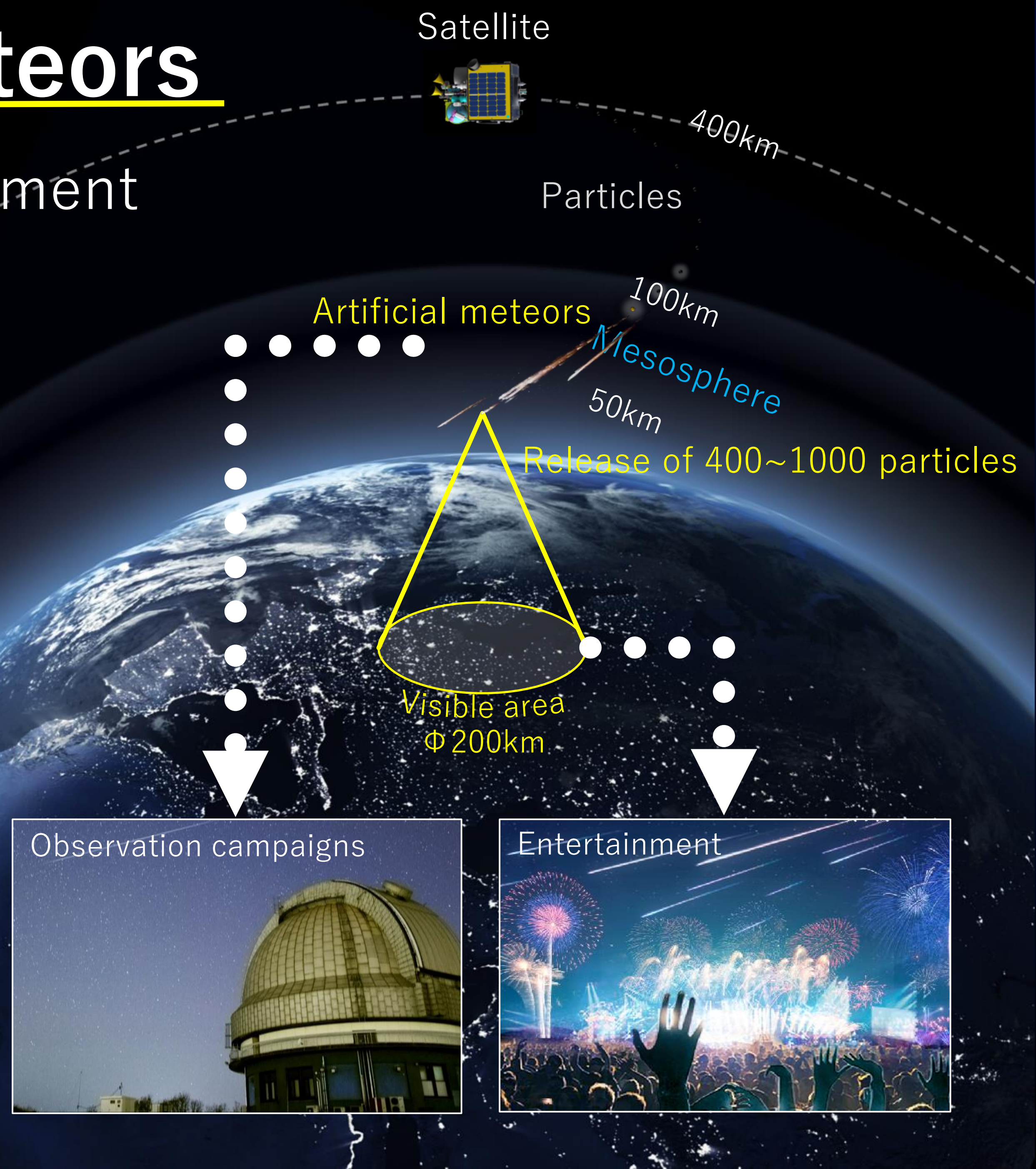




Precursor Ionization

…To man-made meteors

- Provide an unprecedented entertainment
- Infuse Science with People:
  - upper atmosphere mysteries,
  - materials and plasma sciences
- Provide flight data to contribute to:
  - weather forecast and climate change
  - spacecraft design
  - space debris fragmentation and mitigation
  - foreign bodies signature and detection



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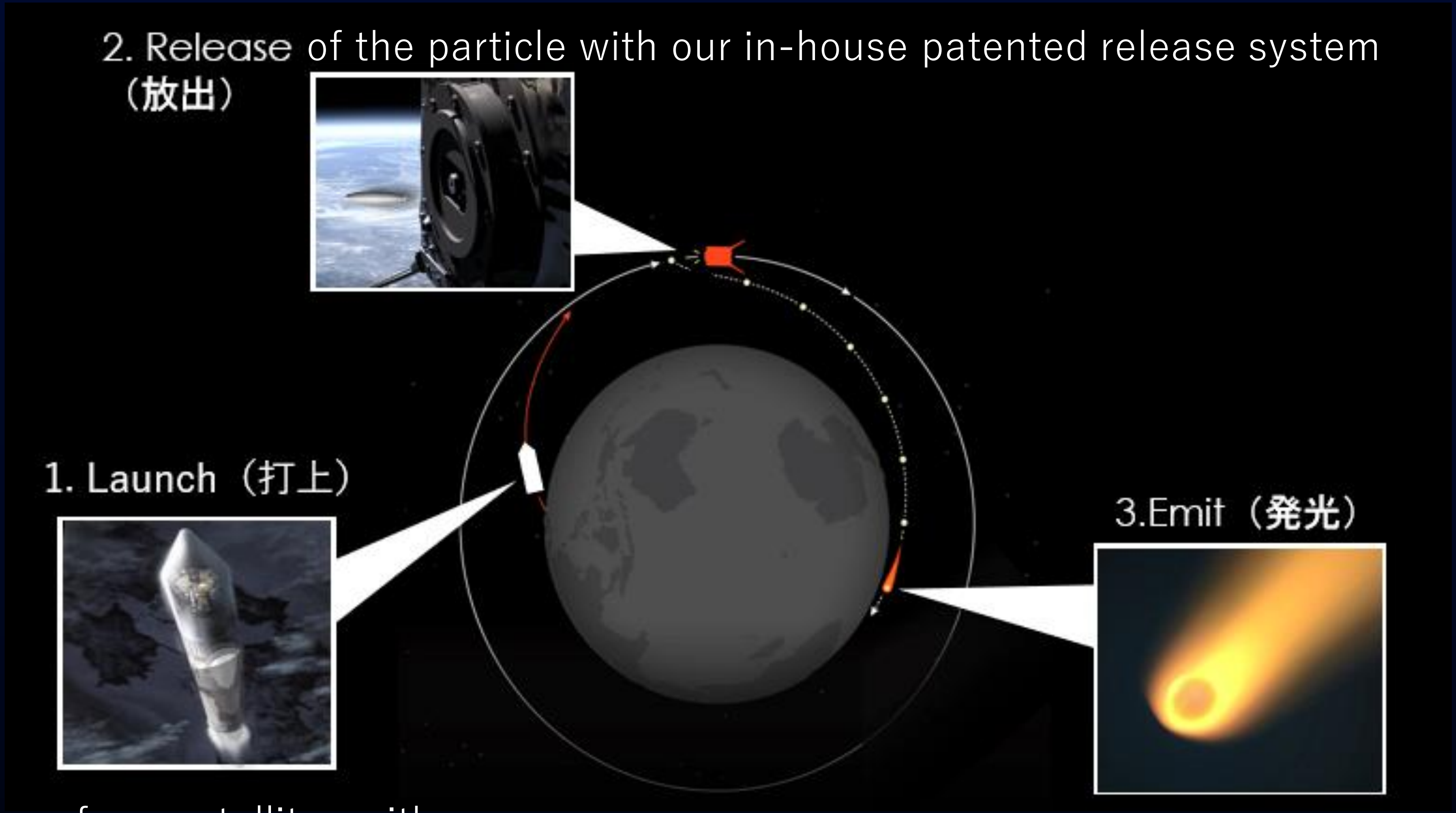
Technologies

A small satellite + A particle release system + A particle

satellite specifications	
Weight	65 kg
Size	450 x 430 x 720 mm

Mission sequence



2. Release of the particle with our in-house patented release system

1. Launch of our satellites with most likely private launch company

3. Emit by leveraging aero-heating and ablation of a non-toxic confidential material

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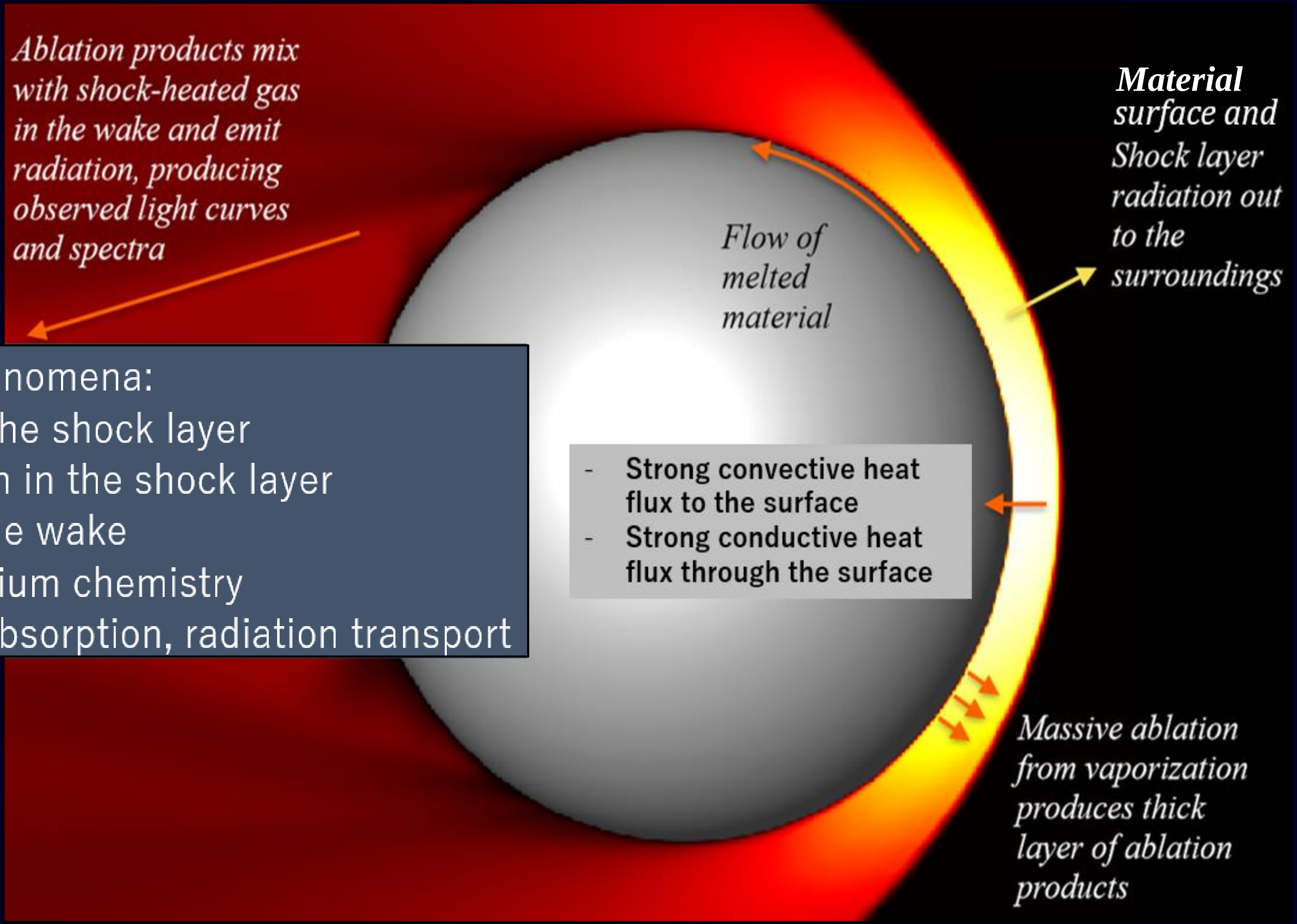
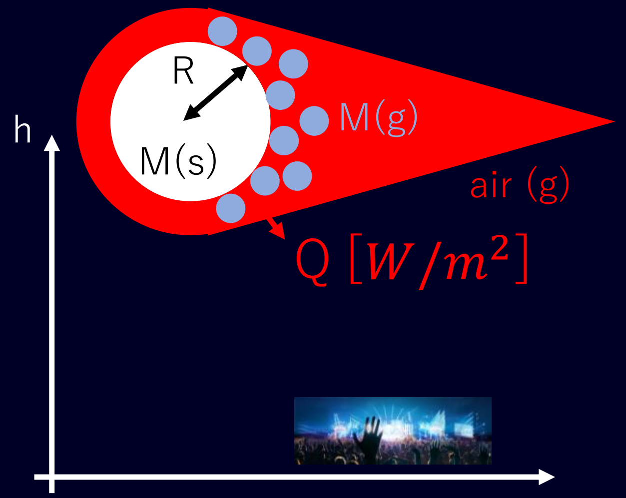
Shooting Star Wake Physics (Stern et al., 2017)



Governing phenomena:
- melting in the shock layer
- vaporization in the shock layer
- mixing in the wake
- nonequilibrium chemistry
- emission, absorption, radiation transport

Hybrid Loosely-Coupled Approach

■ Basics



$$Q = Q_{M(s)} + Q_{M(g)} + Q_{air(g)}$$

$$I = \mathrm{Q}\frac{\pi R^2}{2\pi h^2}\ [W/m^2]$$

$$M = m_0 - 2.5log_{10}\left(\frac{I}{I_0}\right)$$

$$m_0 = -26.74$$

$$I_0 = 1.36\ [kW/m^2]$$

■ Assumptions

- Particles ejected from material in the gas phase
- No chemical reactions between air and material
- Material temperature given by radiative equilibrium

■ Computation of the radiative heat flux Q

- Mass loss with from trajectory model or mass loss measurements
- Flow and brightness computations with CFD, DSMC and radiation codes

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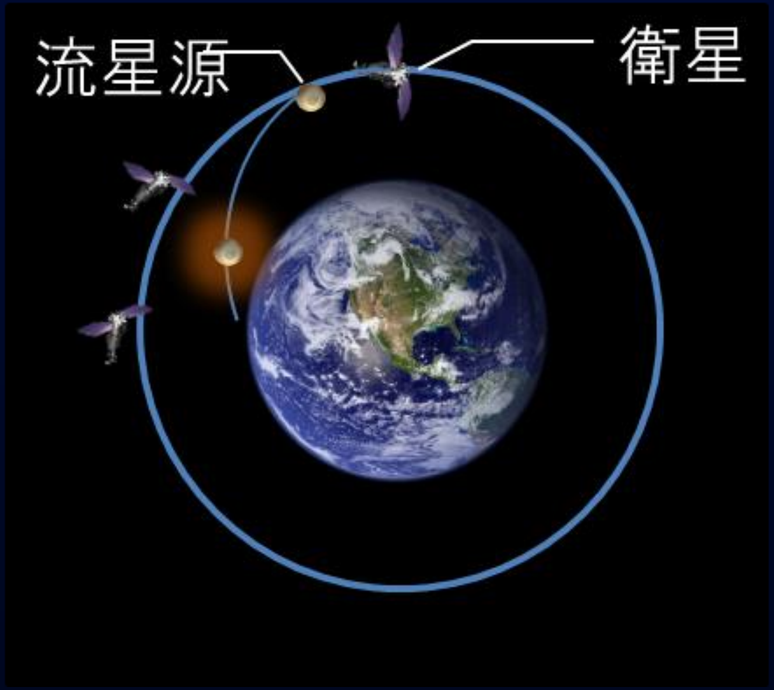
Initial conditions



Time of release	2020/01/01 0:0:0 (UTC)
Coordinates	W43° N60° from 375km
Initial speed	7.33 km/s

Governing trajectory equations

Atmosphere model: NRLMSISE-00
Heat flux models: DKR with and without mass blowing correction

Momentum

$$m\frac{\mathrm{d}^2\boldsymbol{r}}{\mathrm{d}t^2} = -\nabla U(\boldsymbol{r}) \quad -\frac{1}{2}C_\mathrm{d}S\rho\boldsymbol{v}^2\frac{\boldsymbol{v}}{|\boldsymbol{v}|}$$

Mass loss

$$L^*\frac{\mathrm{d}m}{\mathrm{d}t} = -\frac{1}{2}C_\mathrm{h}S\rho v^3 \qquad S = S_\mathrm{e}\left(\frac{m}{m_\mathrm{e}}\right)^\nu$$

Brightness

$$I = -\tau\frac{\mathrm{d}E}{\mathrm{d}t} \qquad E = \frac{1}{2}mv^2$$

C_d (Hindenberg et al., 1965)

$$C_\mathrm{d} = \frac{0.9 + \frac{0.34}{Ma^2} + 1.86\left(\frac{Ma}{Re}\right)^{\frac{1}{2}}\left[2 + \frac{2}{Sa^2} + \frac{1.058}{Sa}\left(\frac{T_\mathrm{m}}{T}\right)^{\frac{1}{2}} - \frac{2}{Sa^4}\right]}{1 + 1.86\left(\frac{Ma}{Re}\right)^{\frac{1}{2}}}$$

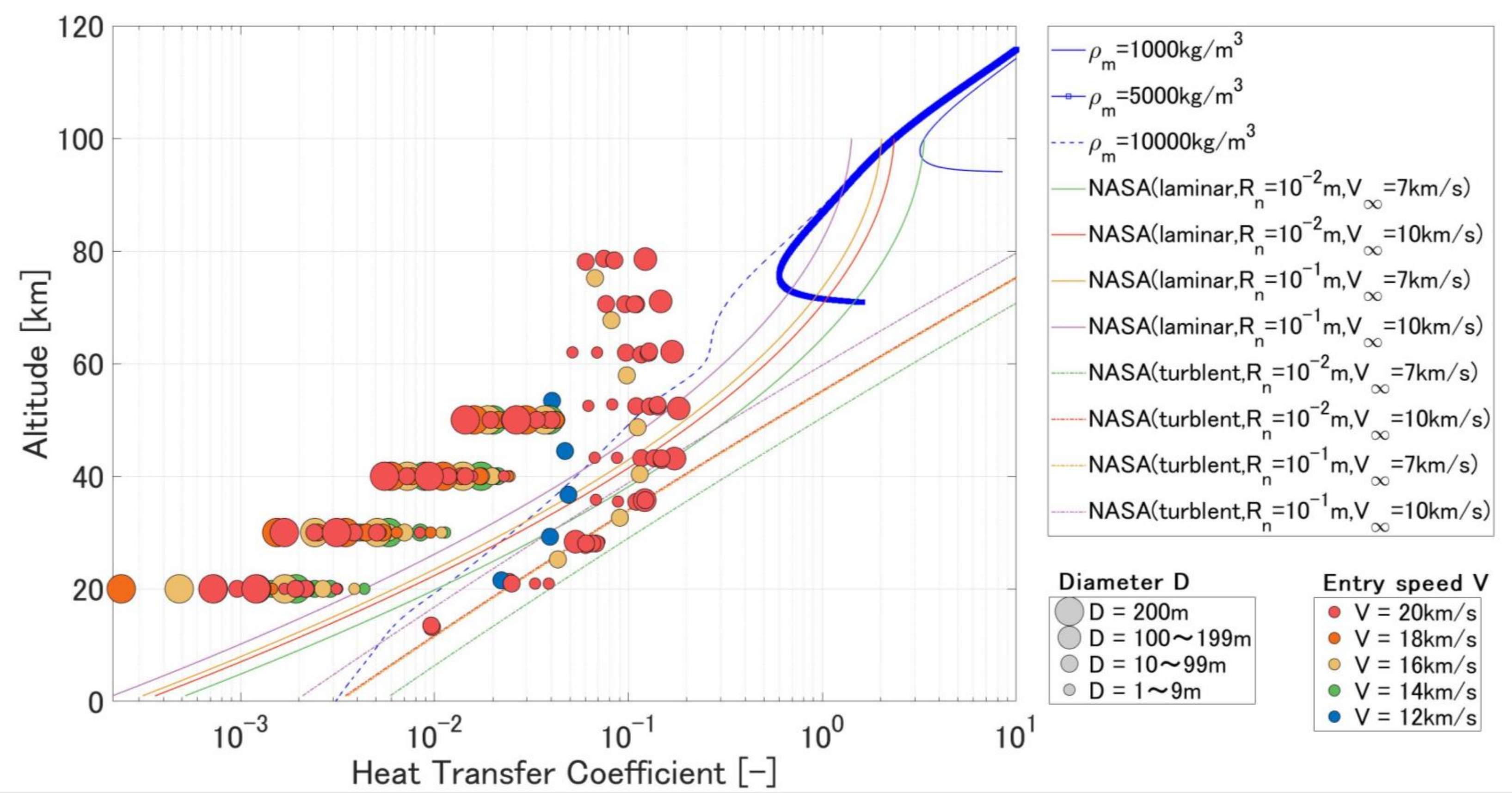
$$Sa = Ma\sqrt{(\gamma/2)}$$

C_h (Prevereaud et al., 2017)

$$C_\mathrm{h} = \frac{2q}{\rho v^3}\frac{\int_0^{\frac{\pi}{2}}\left[\sin^2(\theta) + \frac{\cos^2(\theta)}{1+\gamma Ma^2}\right]\left(\frac{\pi}{2} - \theta\right)\cos(\theta)\sin(\theta)\,\mathrm{d}\theta}{\sqrt{\int_0^{\frac{\pi}{2}}\left[\sin^2(t) + \frac{\cos^2(t)}{1+\gamma Ma^2}\right]\left(\frac{\pi}{2} - t\right)\cos^2(t)\,\mathrm{d}t}}$$

Computations

Comparison with:
- computations (Johnston et al., 2017) and,
- correlations (Prabhu et al., 2016)



Conclusions: extensive work required for small meteors (Park et al., 2016)

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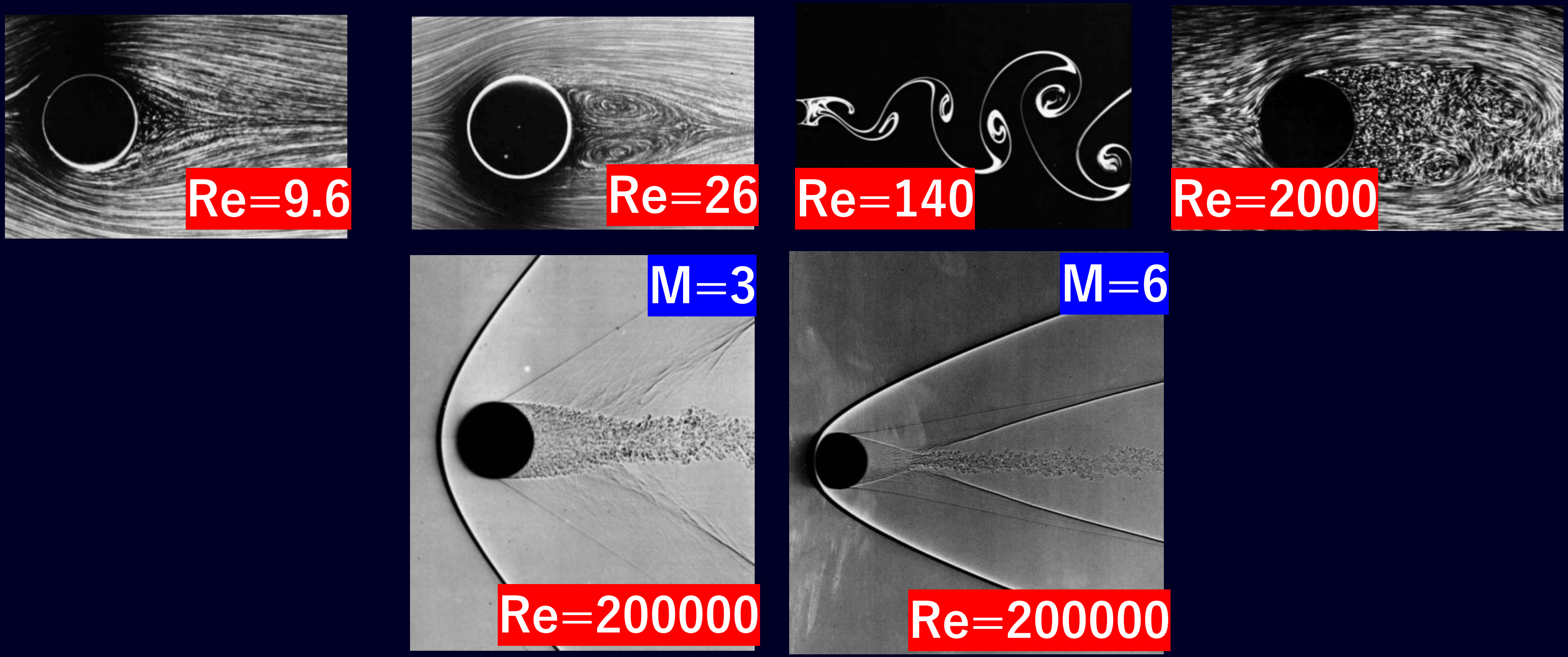
Fundamentals of Wake Flows

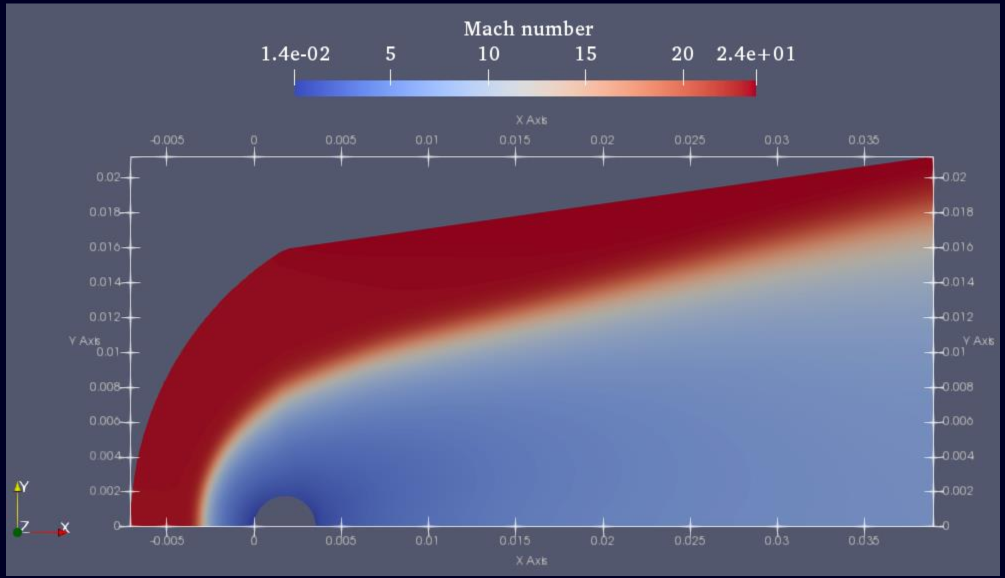
- Key Parameter: Post-Shock Reynolds Number Re
- Characteristic dimensions: - height ~ 1/Re^0.5

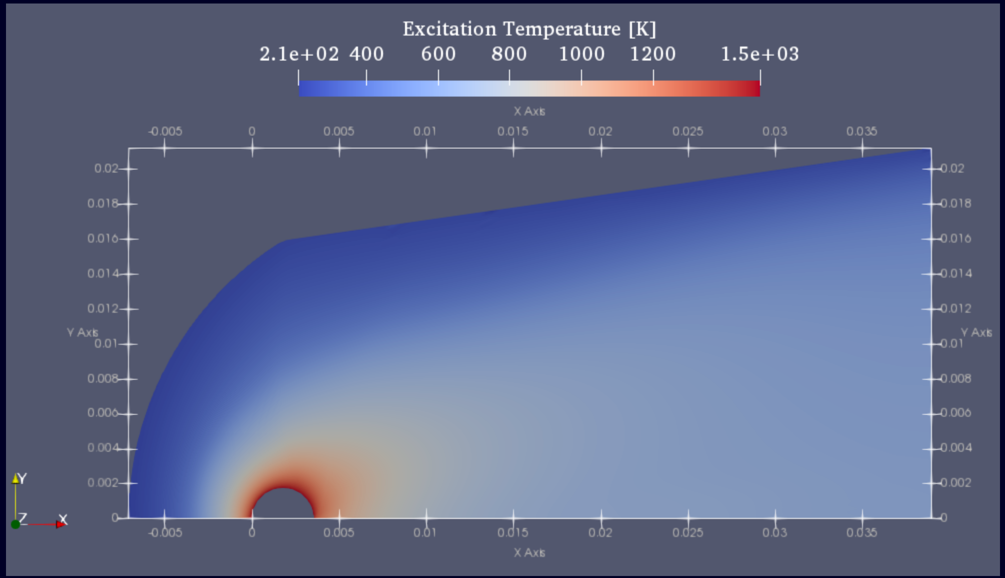
  - length ~ Re^0.5



Aerodynamics

- JAXA JONATHAN code
  - stable, cost-effective
  - multi-temperature model
  - Maxwell boundary conditions
  - tailored for:
    - high nonequilibrium
    - transition flows
- ALE code tailored for
  - Rarefied flows
  - Hypersonic flows
- US DoE SPARTA code
  - Rarefied flows
  - Nonequilibrium flows
  - Hypersonic flows





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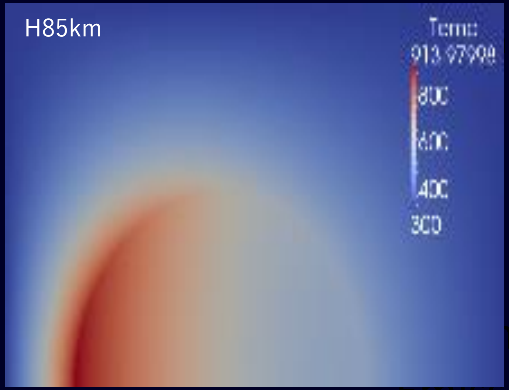
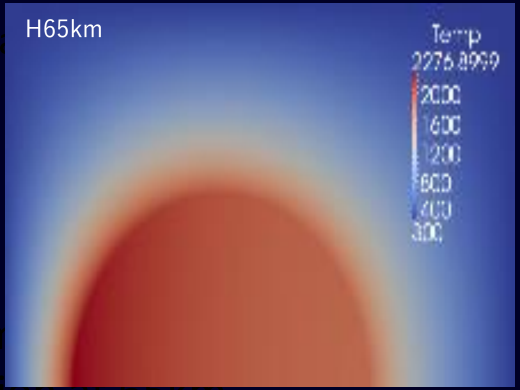
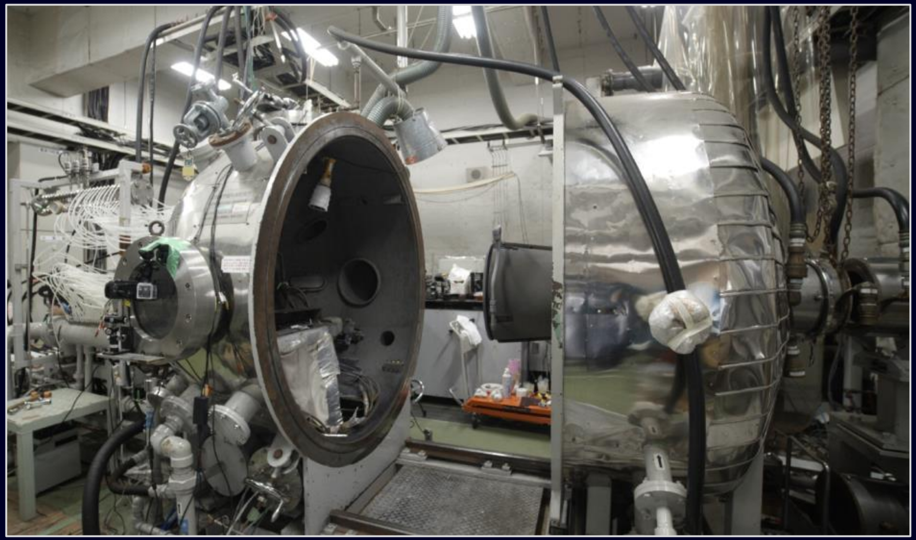
Material Thermal Response

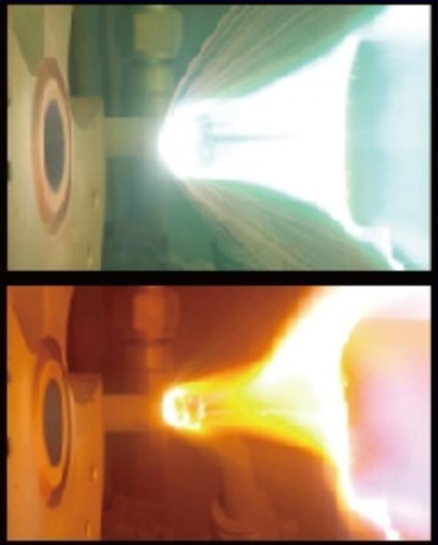
- Simulations with ALE in-house code





- Plasma Wind tunnel tests at JAXA ISAS facility

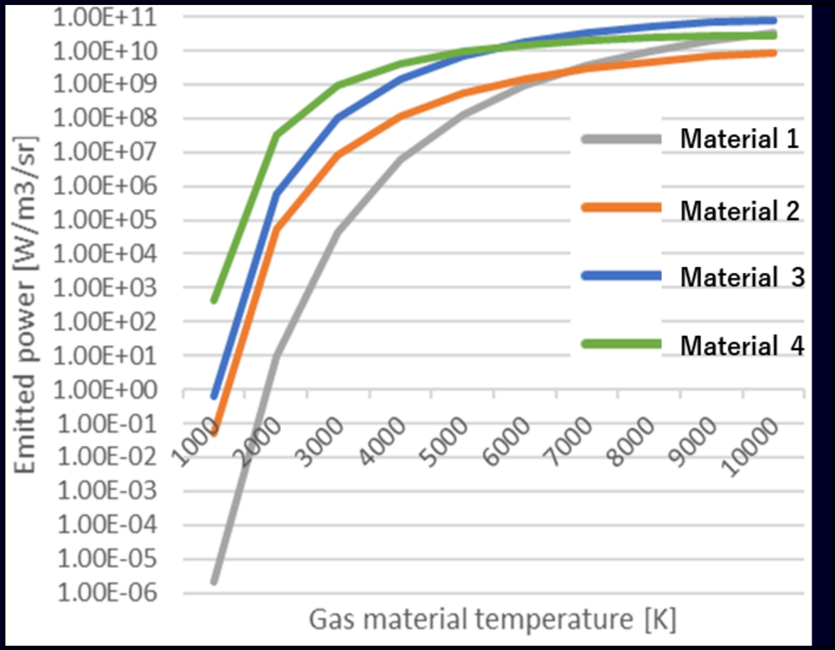




- Conclusion: Material ablation compliant with safety requirement

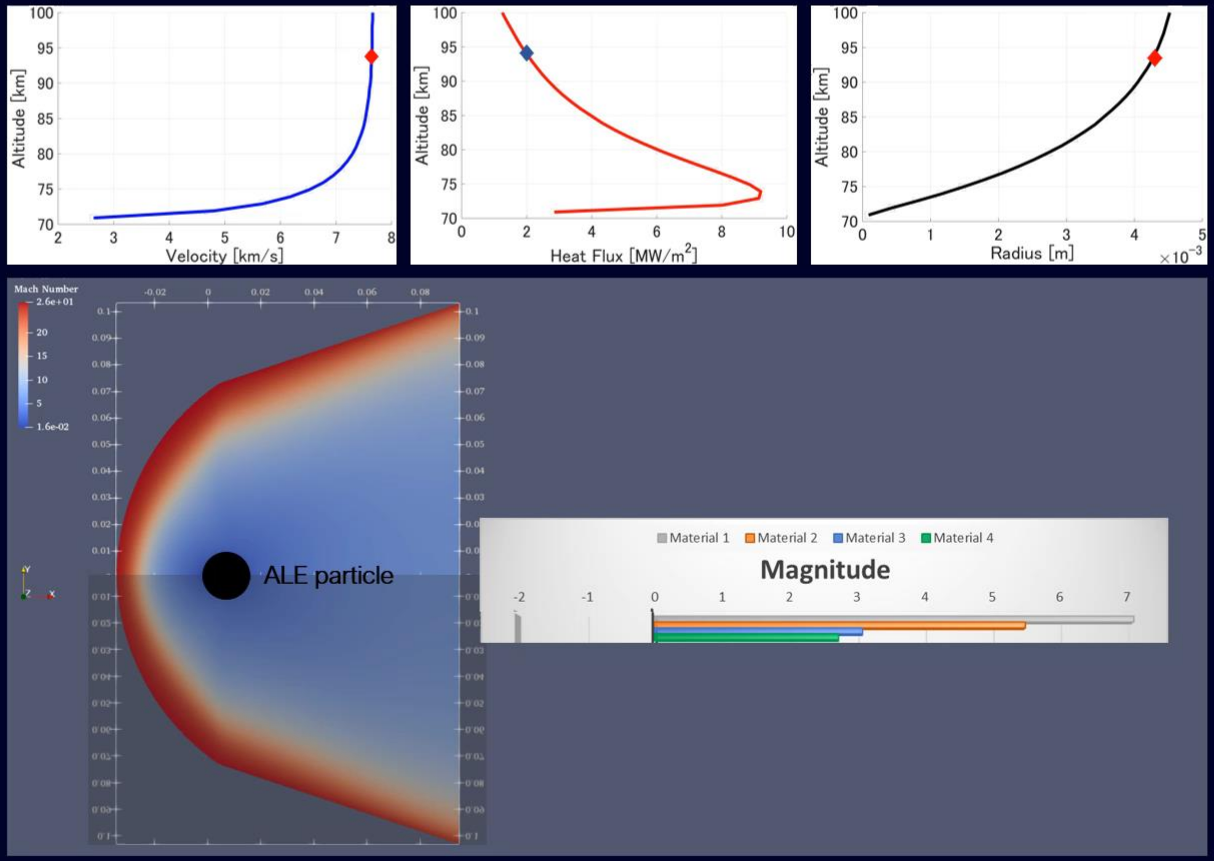
Emission

- Spectral properties with ALE in-house code
  - Multi-options transport model for brightness evaluation
  - High flexibility for multi-species flow brightness
  - Computation of Franck-Condon factors (Laux et al., 1993)



- Conclusions:
  - Significant brightness from some materials
  - Possible multi-material selection and composition optimization

Shooting Star Simulated Earth's Entry



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Milestones and Time Frame

- January 2019:
  - ALE-1 satellite launched on-board JAXA Epsilon #4 rocket

- March 2019:
  - Selection to the New Space Global Summit among the 500 start-ups

- April 2019: MOU with JAXA
  - space debris active removal
  - high speed (V>14km/s) sample return missions

- Fall 2019:
  - ALE-2 satellite launch

- Spring 2020, Hiroshima
  - World-first shooting stars event
  - Observation campaign

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Conclusions

- Achievements:
  - In-house, patented particle release system
  - ALE-1 successful launch on board of JAXA Epsilon #4
  - Particles Engineering with simulations, arc-wind tunnels, craftmanship

- Ongoing works:
  - Simulations:
    - DSMC and spectral properties
    - flow-ablation coupling
  - Material test in arc-jets:
    - material thermal response characterization
    - multi-colors materials and optimized mixtures for enhanced brightness
  - A.I. and Data Science
  - International partnerships and contracts

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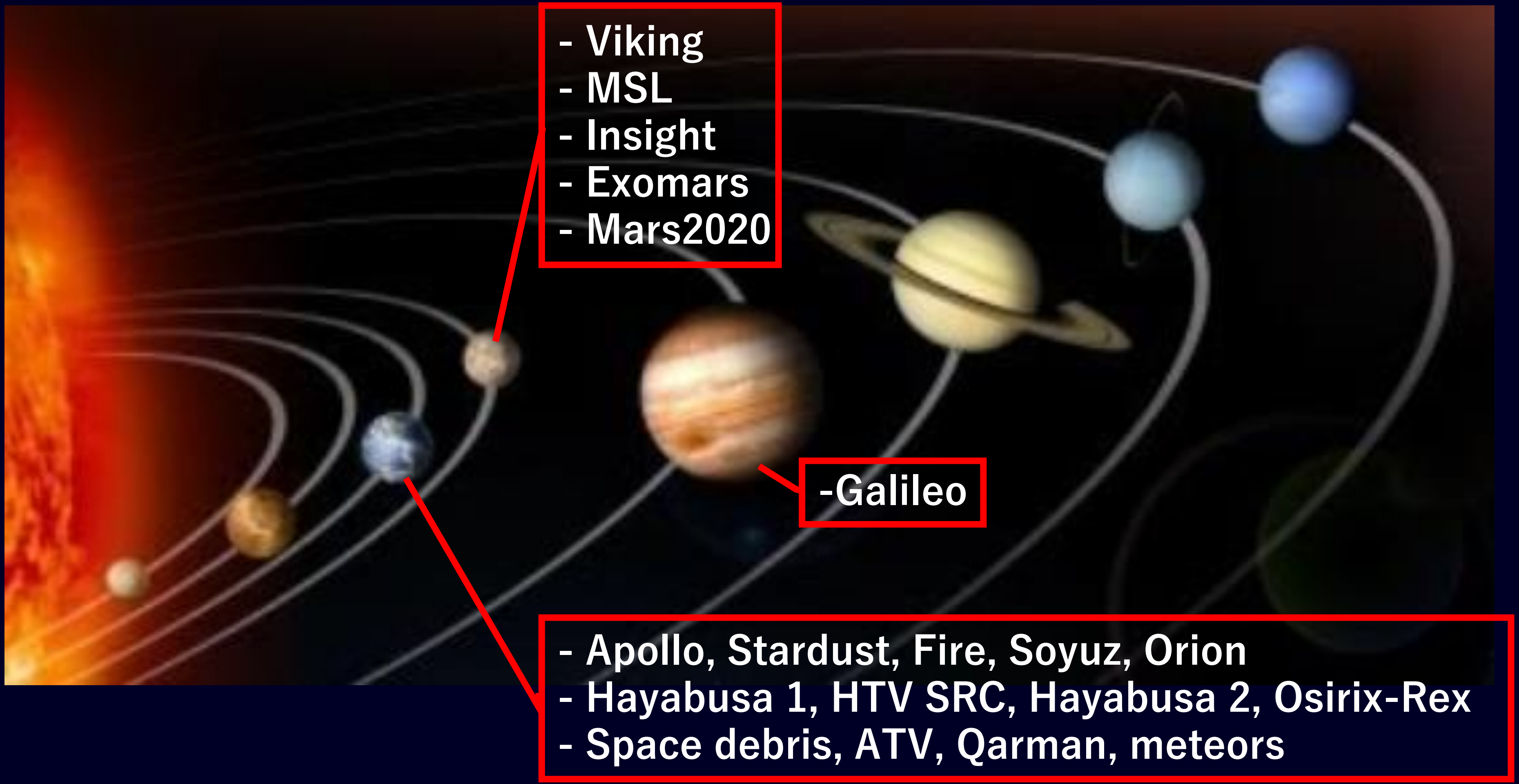
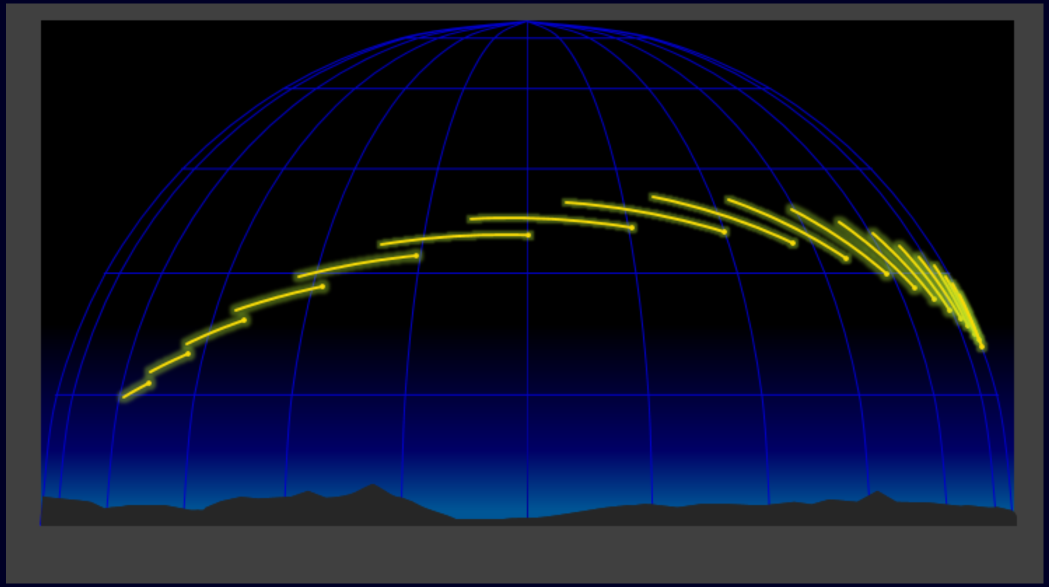
Emission Flight Data



■ Conclusions: - Available data to test models and mitigate uncertainties
- Scarce data

On-demand Flight Data and Partnerships

- We deliver dozen to hundred of particles where and when you want
- We provide a substantial amount of data



- We know:
  - geometry
  - composition, mass
  - nominal trajectory
- We measure:
  - emission spectra
  - radar signatures
  - mass loss rates
- We infer:
  - temperature, composition
  - ionization and chemical reactions
- We advance the knowledge of
  - material fragmentation
  - plasma emission
  - energy conversion
- We contribute to:
  - ✓ weather forecast
  - ✓ heat shields optimization
  - ✓ design for demise
  - ✓ meteor sciences
  - ✓ foreign body detection

Customizable loading systems for:
- R&T activities in space industries,
- R&D and Sciences activities in agencies and universities
- Space entertainment

- Companies, Agencies, Research Departments
  - ✓ Flight-test your space systems with our platform
  - ✓ Flight-test your materials with our system
  - ✓ Measure and analyze on-demand data

Astro Live Experiences

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