Uncertainties and Feedback Control in Mars Entry-Descent-Landing

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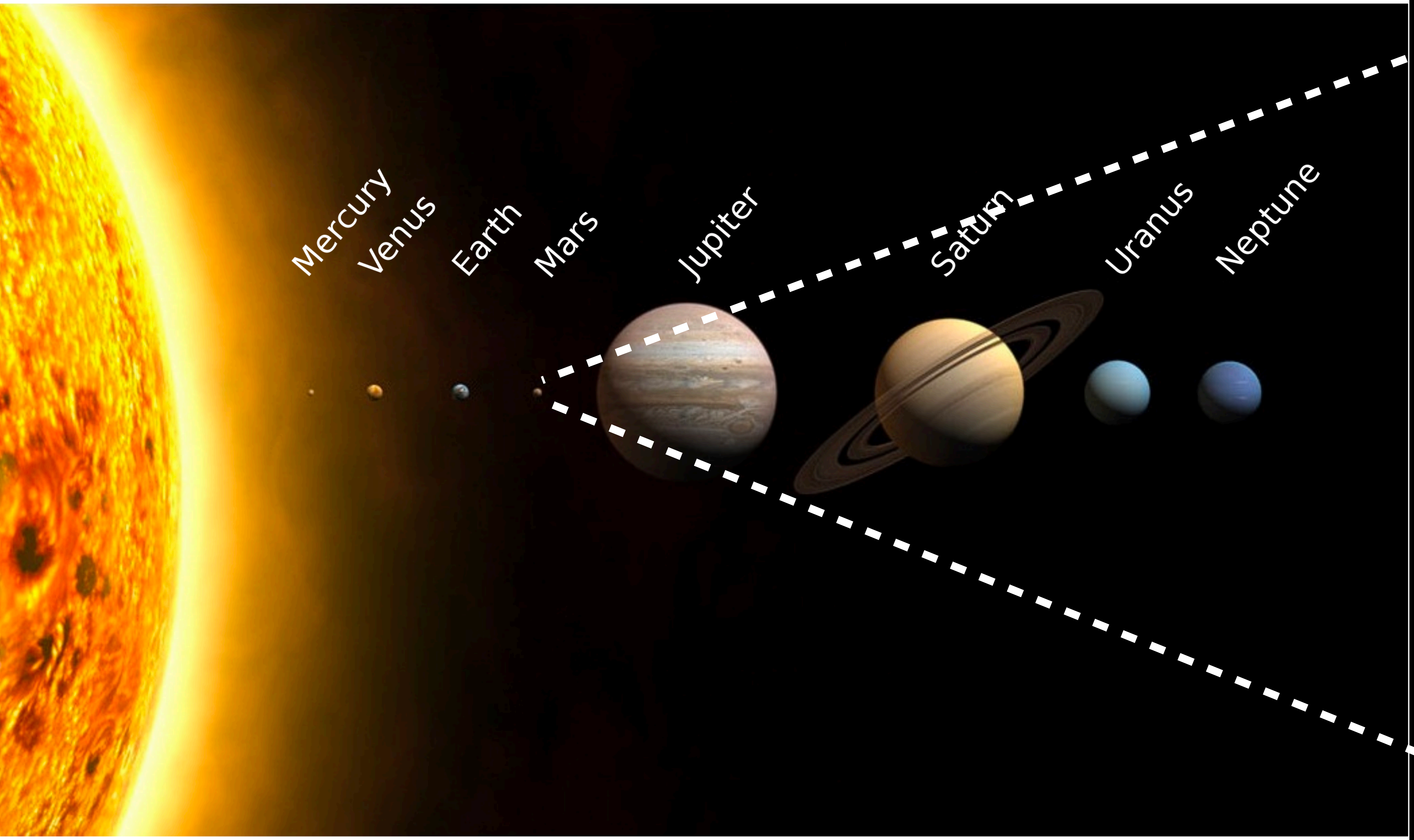
Mars



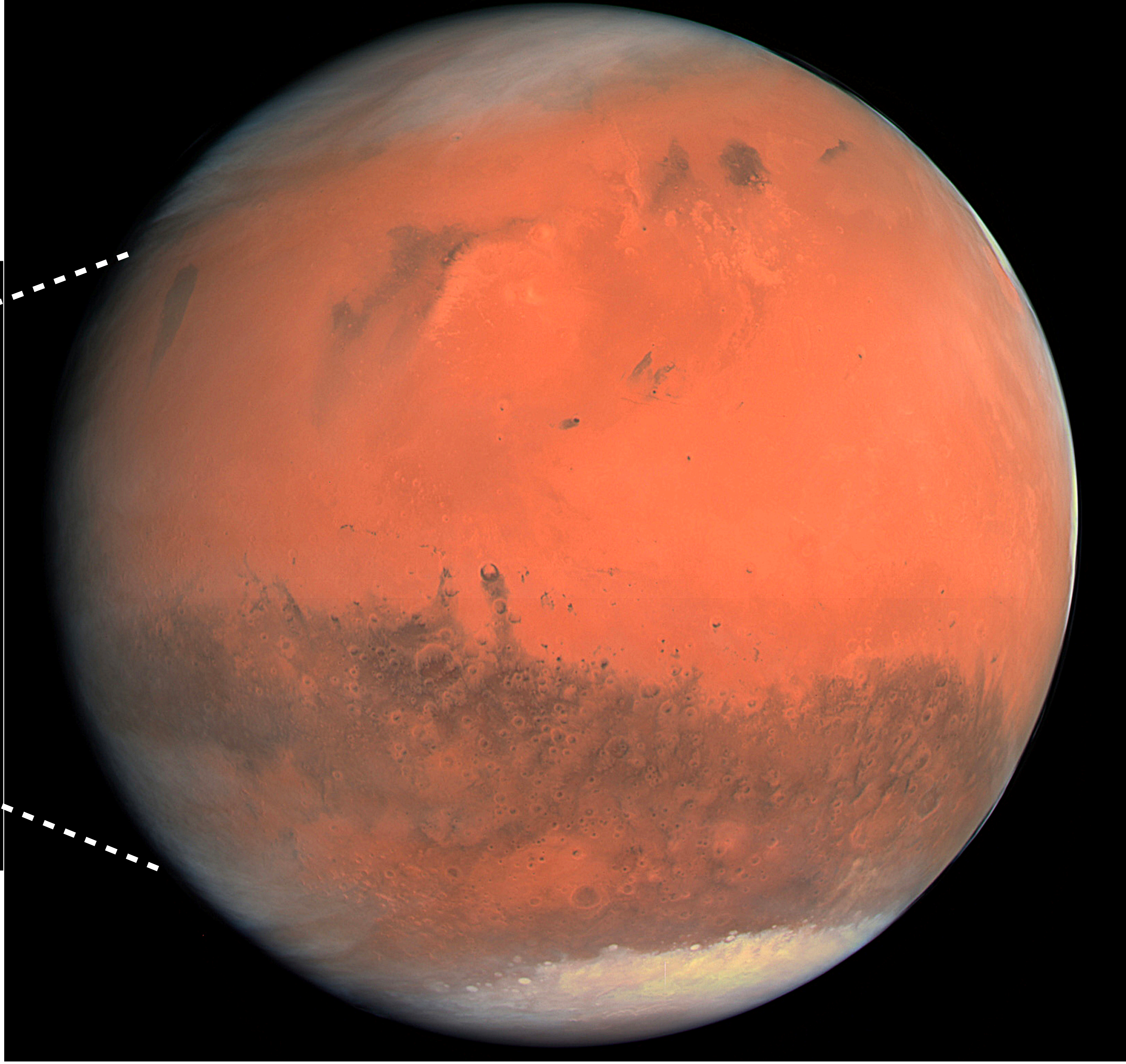
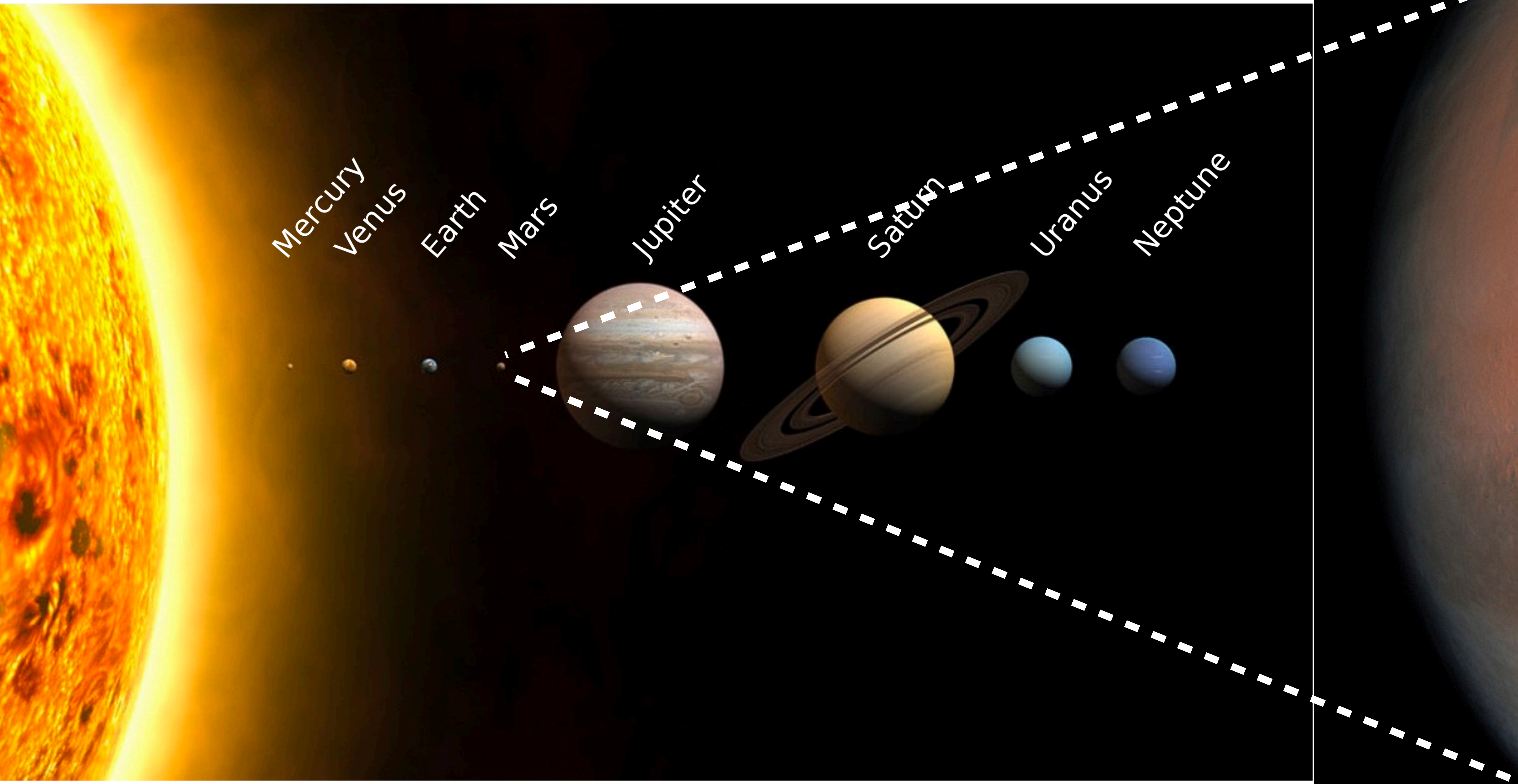


Image Credit: Rosetta spacecraft, European Space Agency, 2007

Mars



Earth to Mars distance ≈ 234 million miles

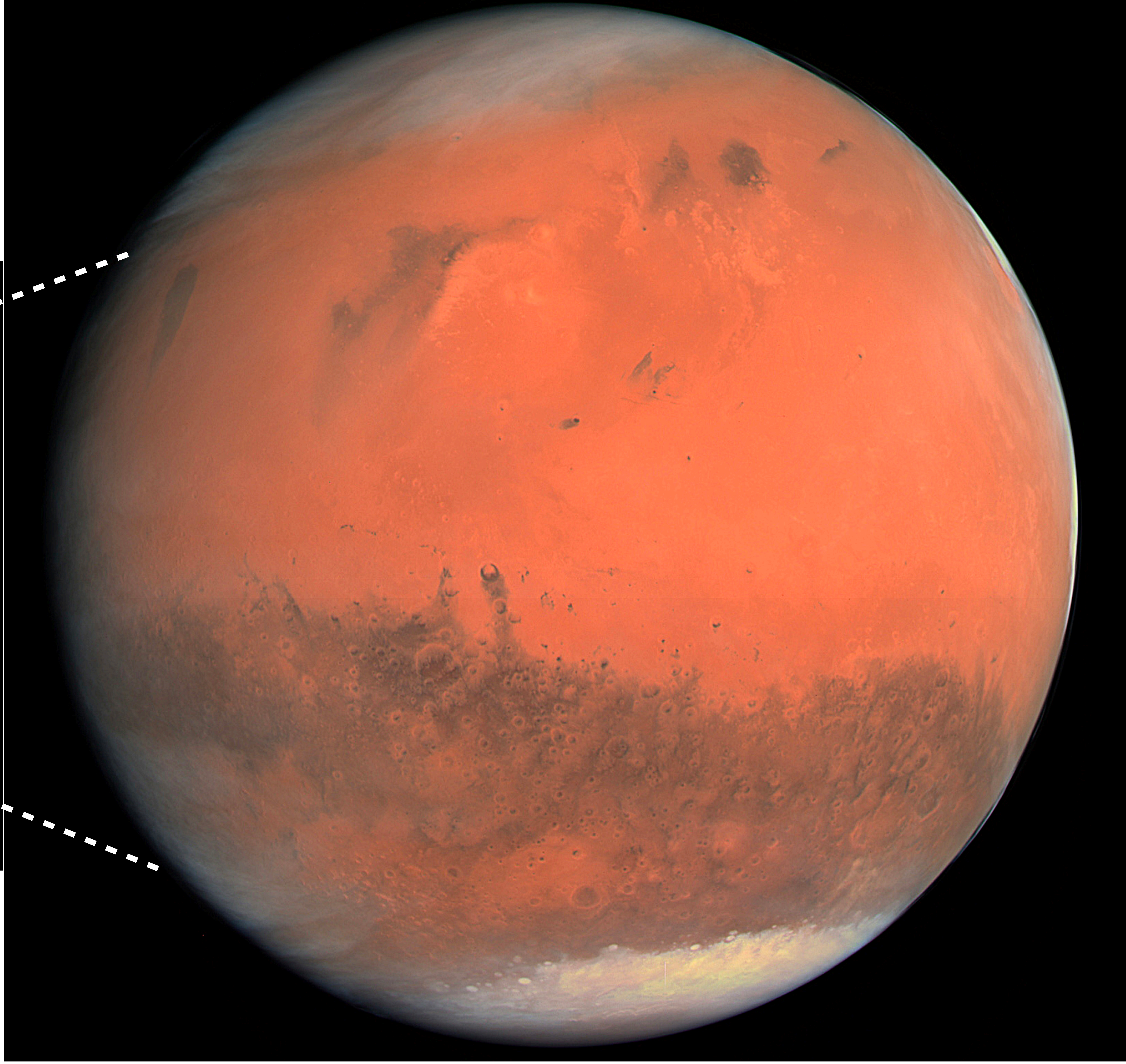
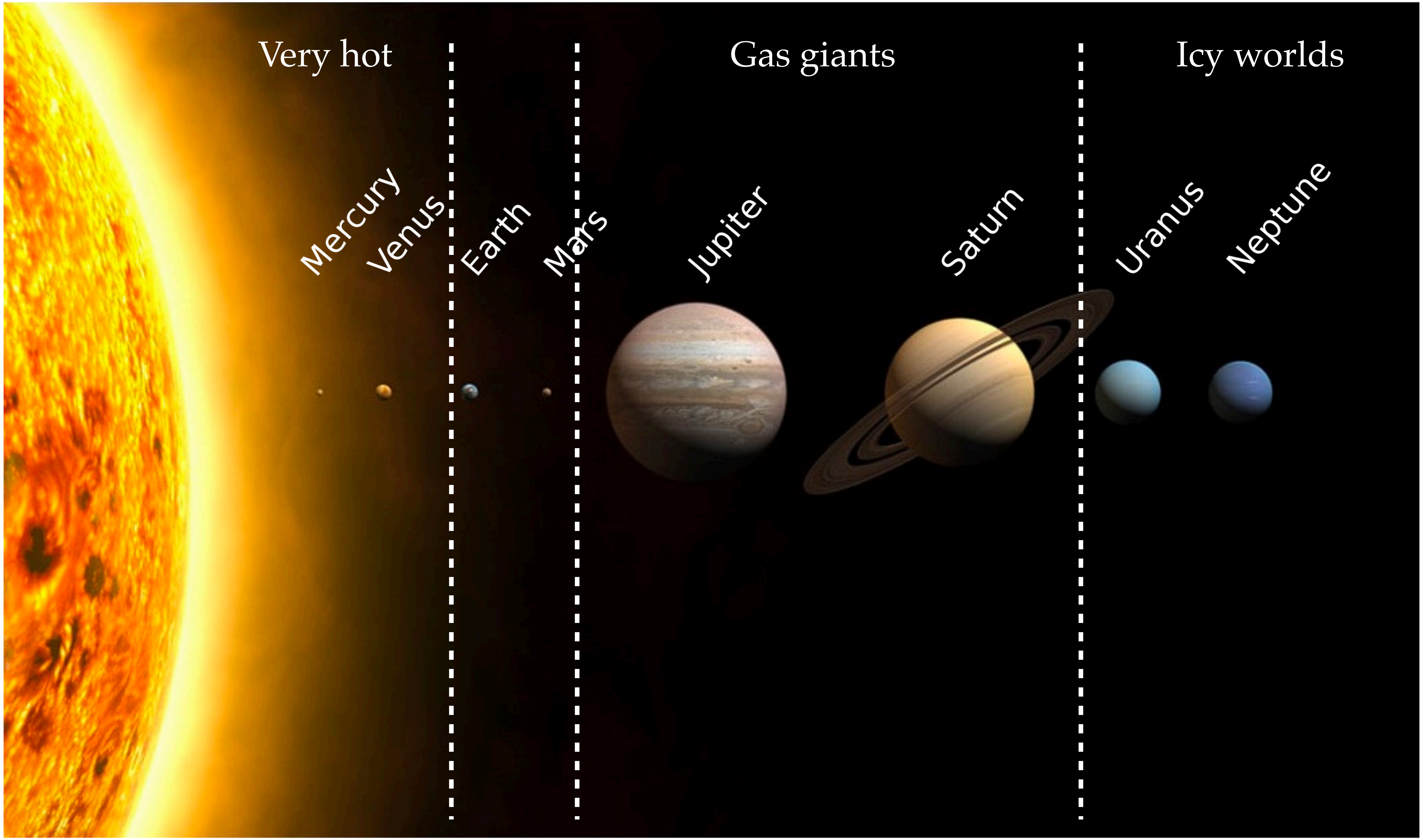


Image Credit: Rosetta spacecraft, European Space Agency, 2007

Why explore Mars



Why explore Mars

1 Mars day ≈ 1.0275 Earth day [24 hr 39 min 36 s]

1 Mars year ≈ 1.8808 Earth year [687 Earth days]

Terrestial planet with rocky core

Water ice caps at its North and South poles

Very strong evidence that liquid water existed in the past

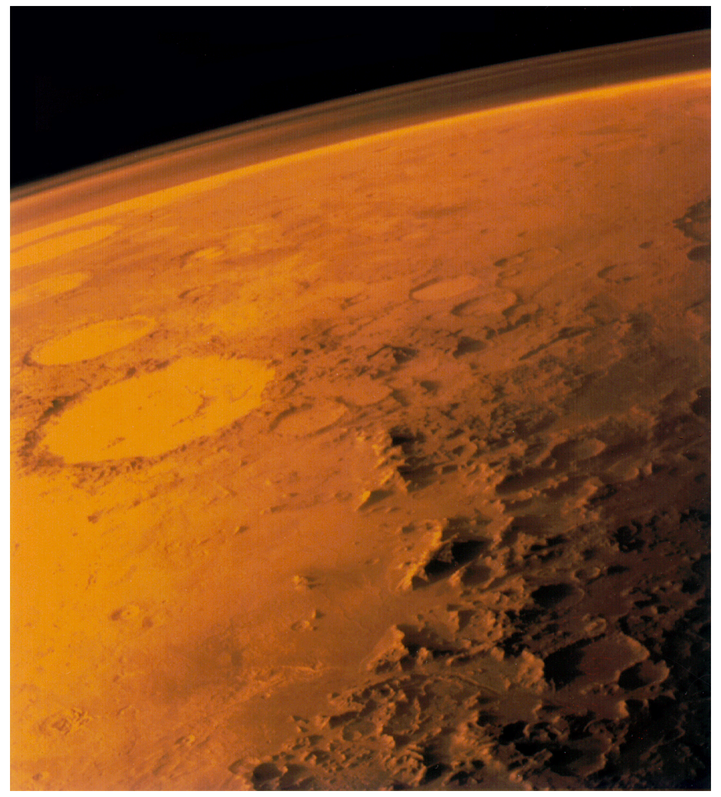
Travel time approx. 7 months

However, landing on Mars is challenging

Mars atmosphere:

95% CO_2
2.8% Nitrogen
2% Argon
rest O_2 and Carbon Monoxide

Very thin (< 1% of Earth)



Earth atmosphere:

78% Nitrogen
21% O_2
1% Argon and other inert gases
0.04% CO_2

Thick

However, landing on Mars is challenging

Sol 2075

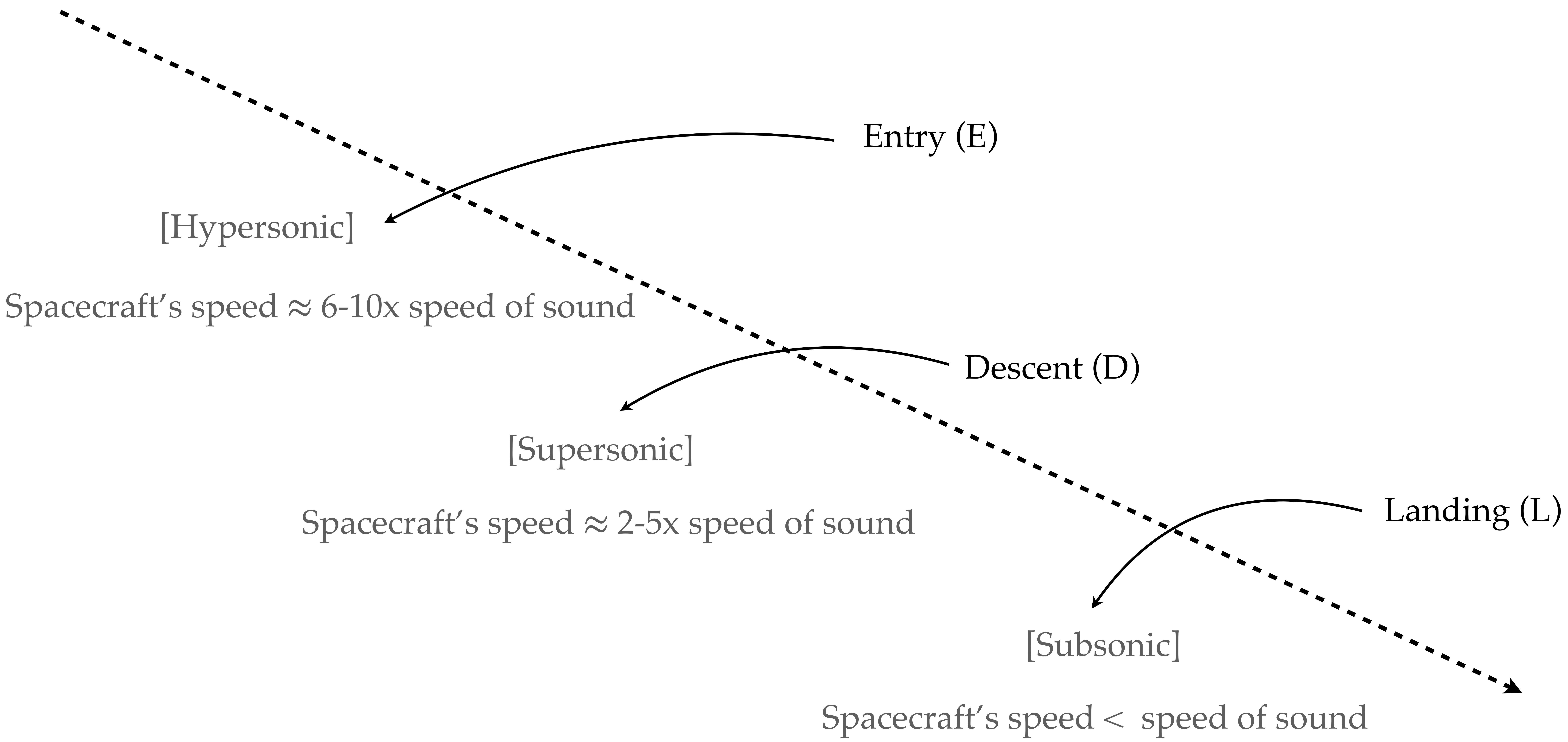
Image Credit: Curiosity rover's mast camera, NASA, 2018

Frequent dust storms

Whole planet-level dust storm in every 3 Mars years

Past NASA landings on Mars

Mars Entry-Descent-Landing (EDL)



Mars EDL

EDL duration $\approx$ 7 minutes [“7 minutes of terror”]

Radio signal travel time $\approx$ 14 minutes during Martian Summer

Requires on-board autonomy and decision making capabilities

Mars EDL: 2021

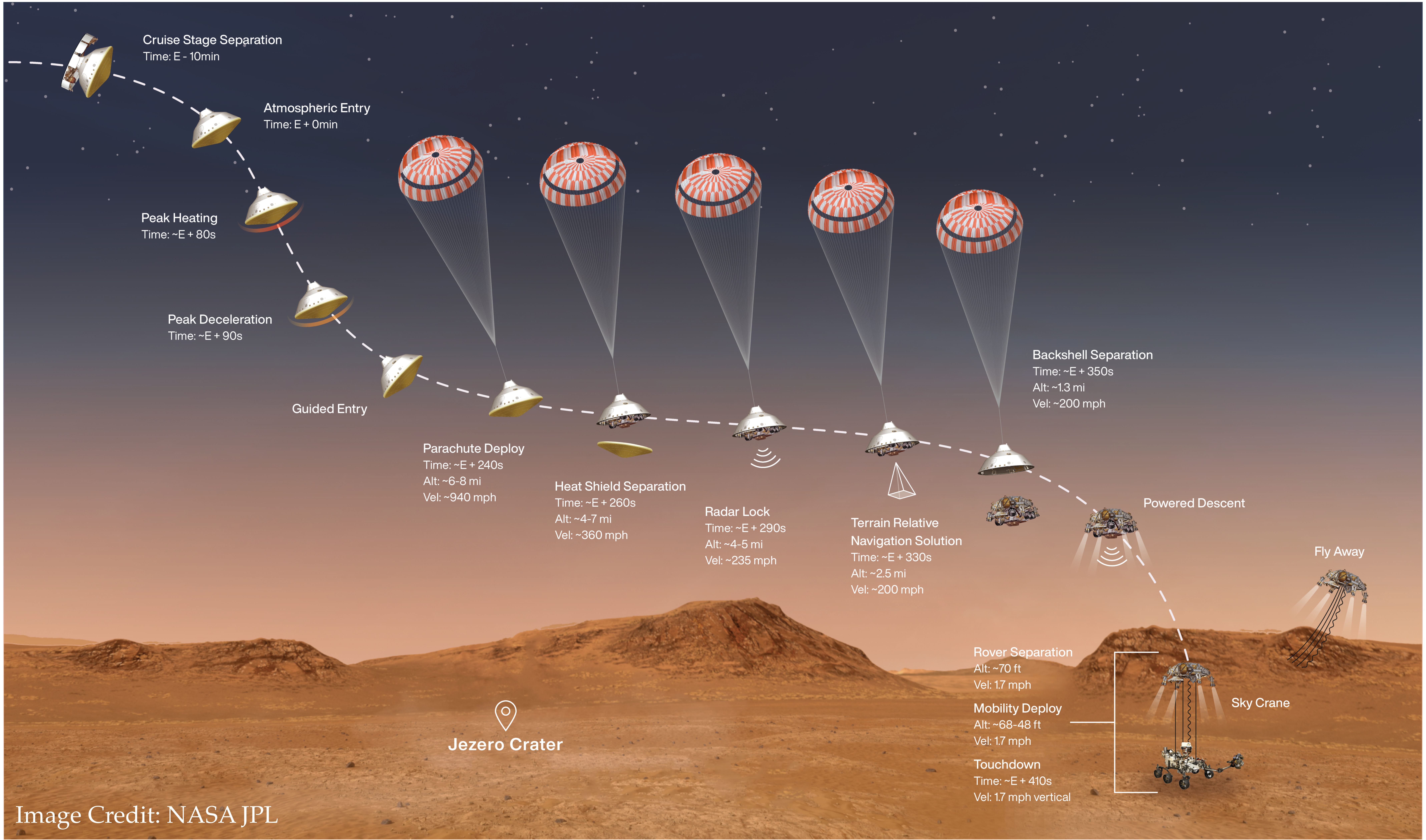
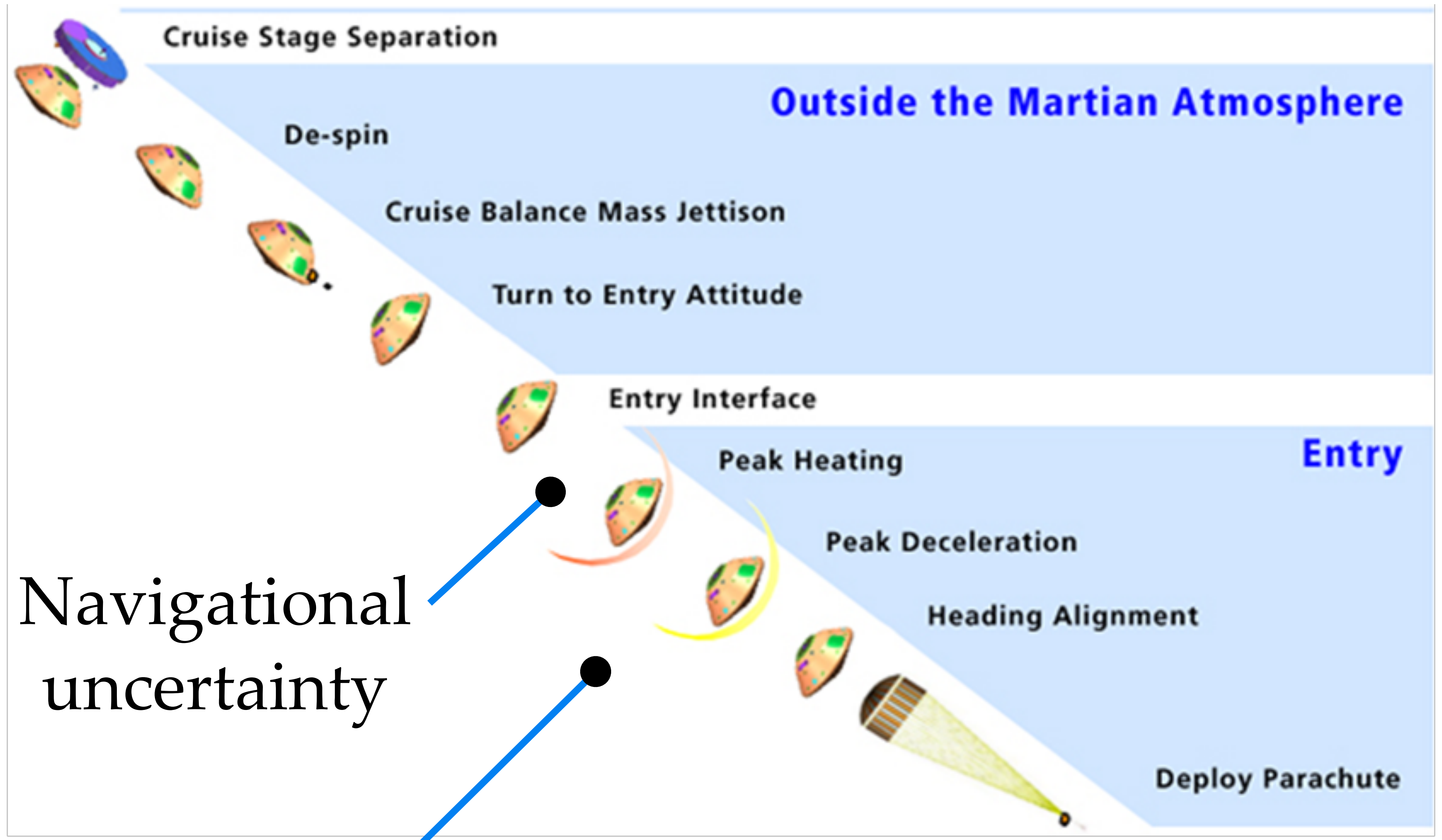


Image Credit: NASA JPL

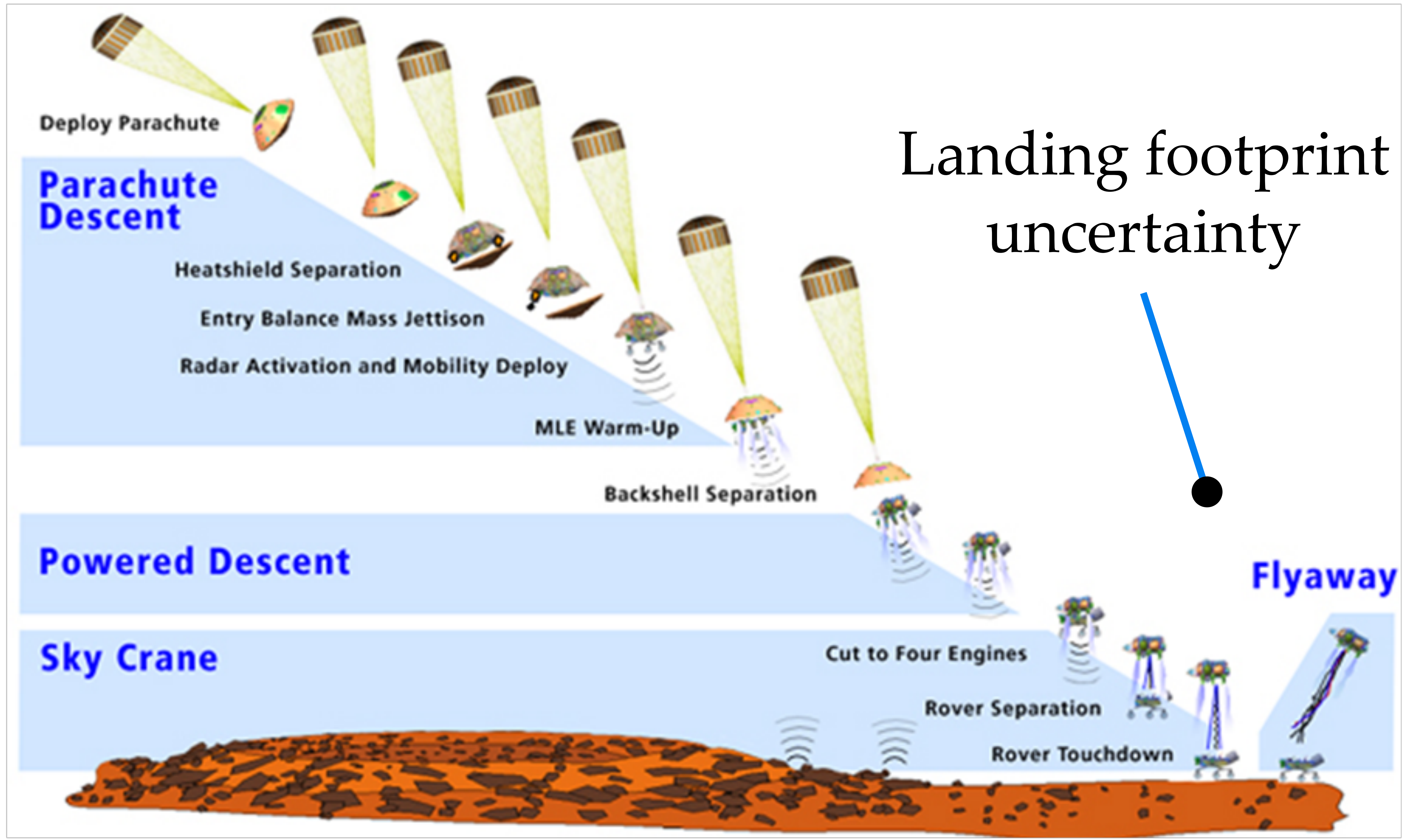
Uncertainties in Mars EDL



Navigational uncertainty

Heating uncertainty

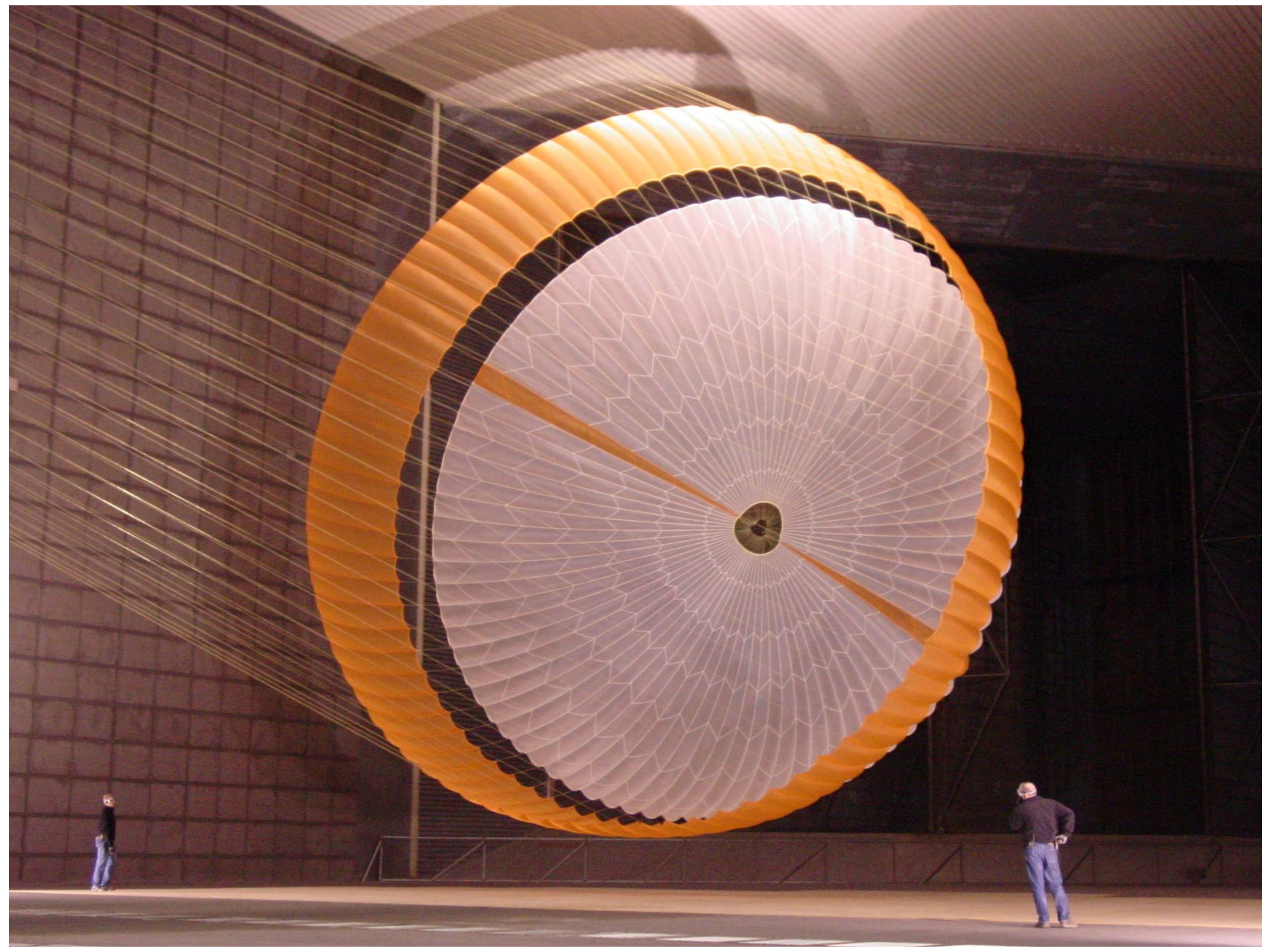
Chute deployment uncertainty



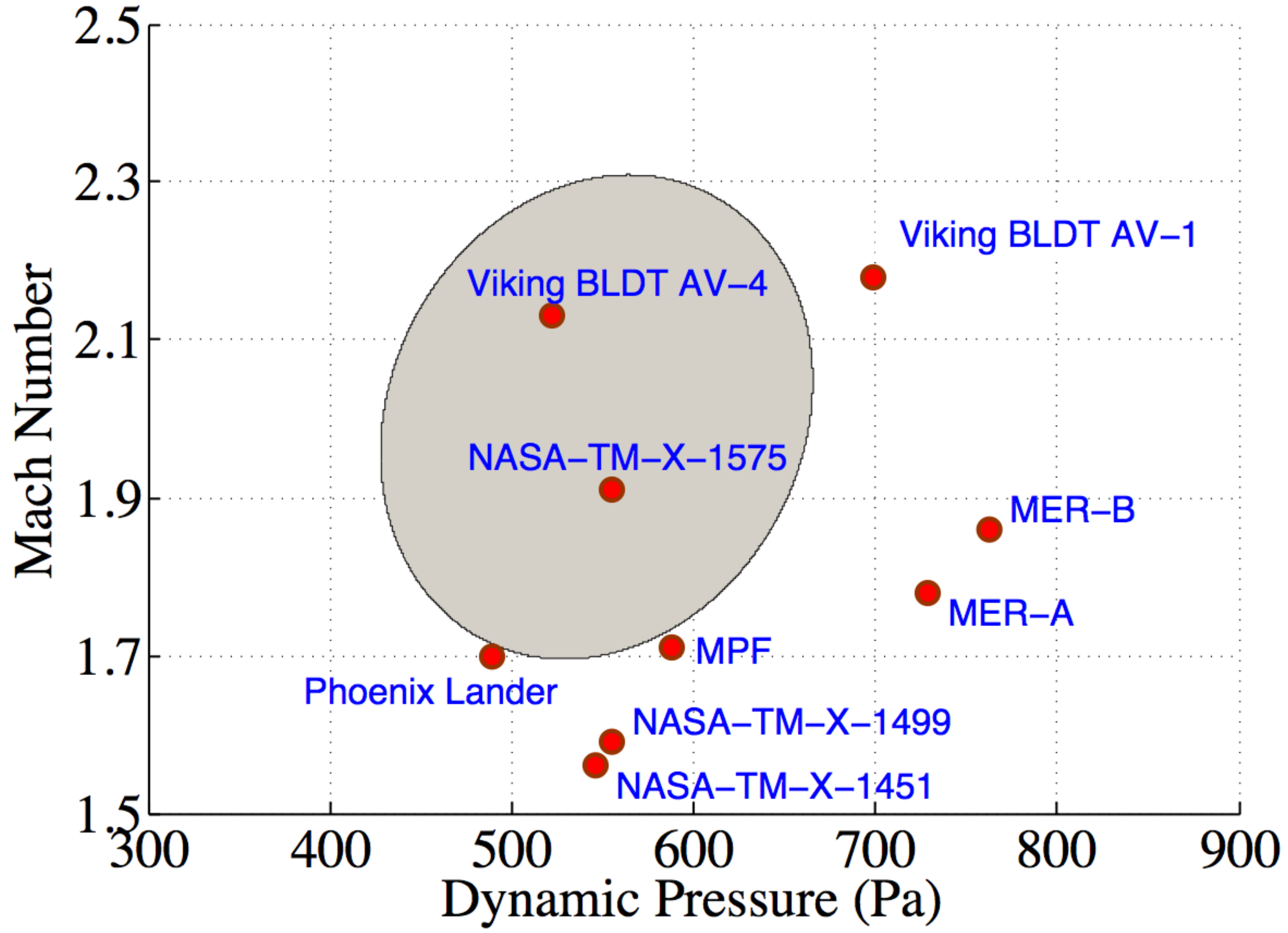
Landing footprint uncertainty

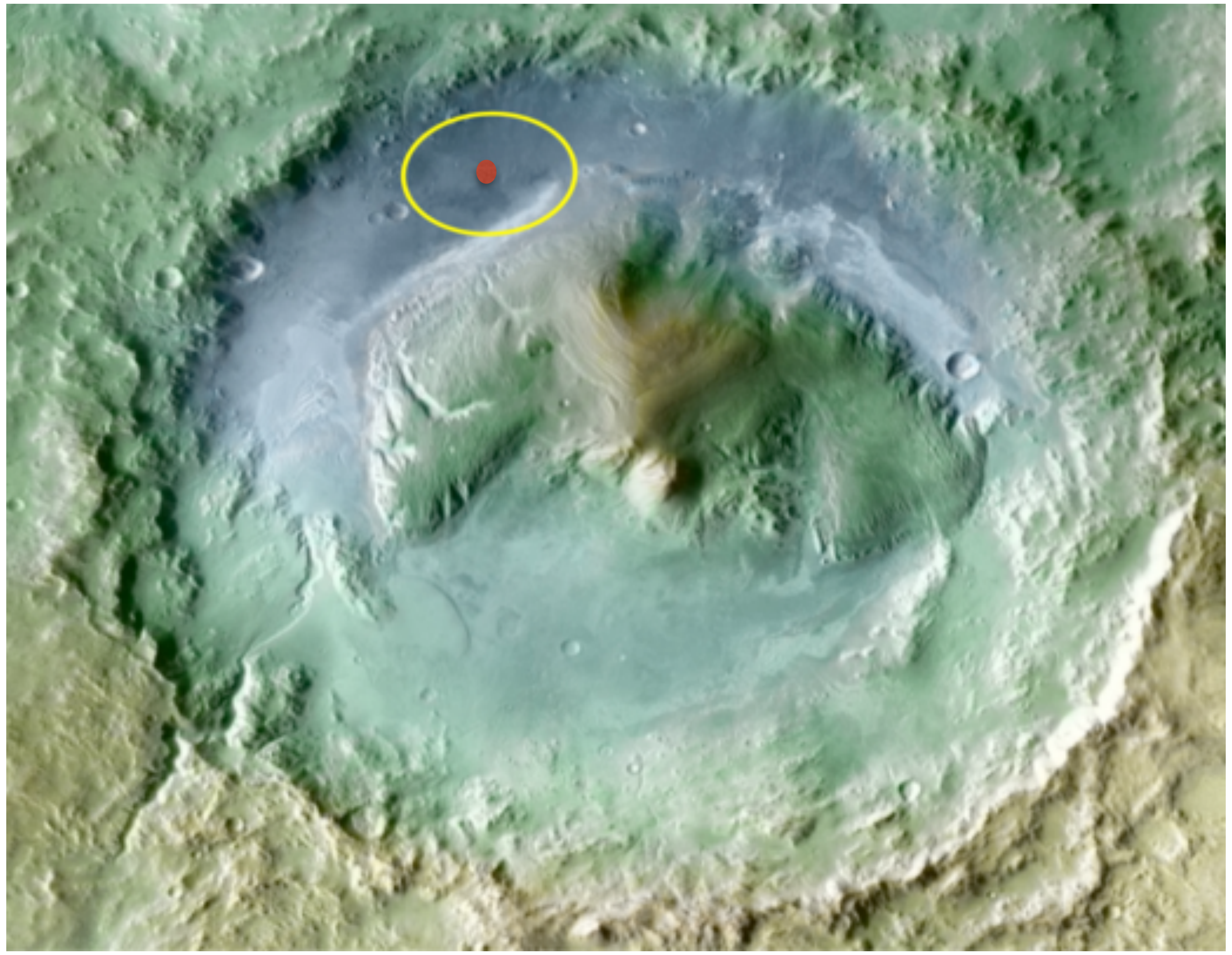
Image credit: NASA JPL

Uncertainties in Mars EDL: prediction, estimation and control



Supersonic parachute

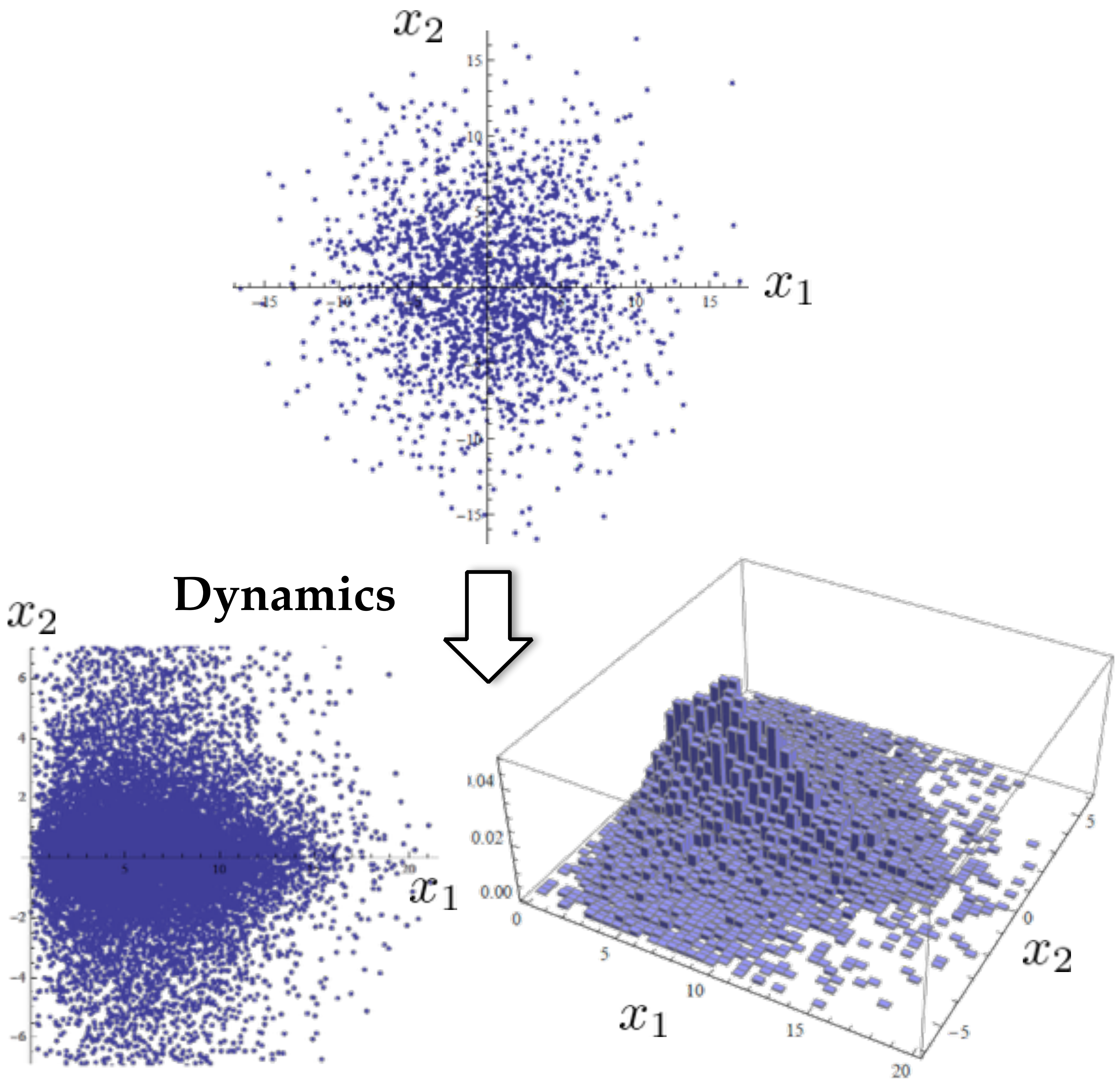




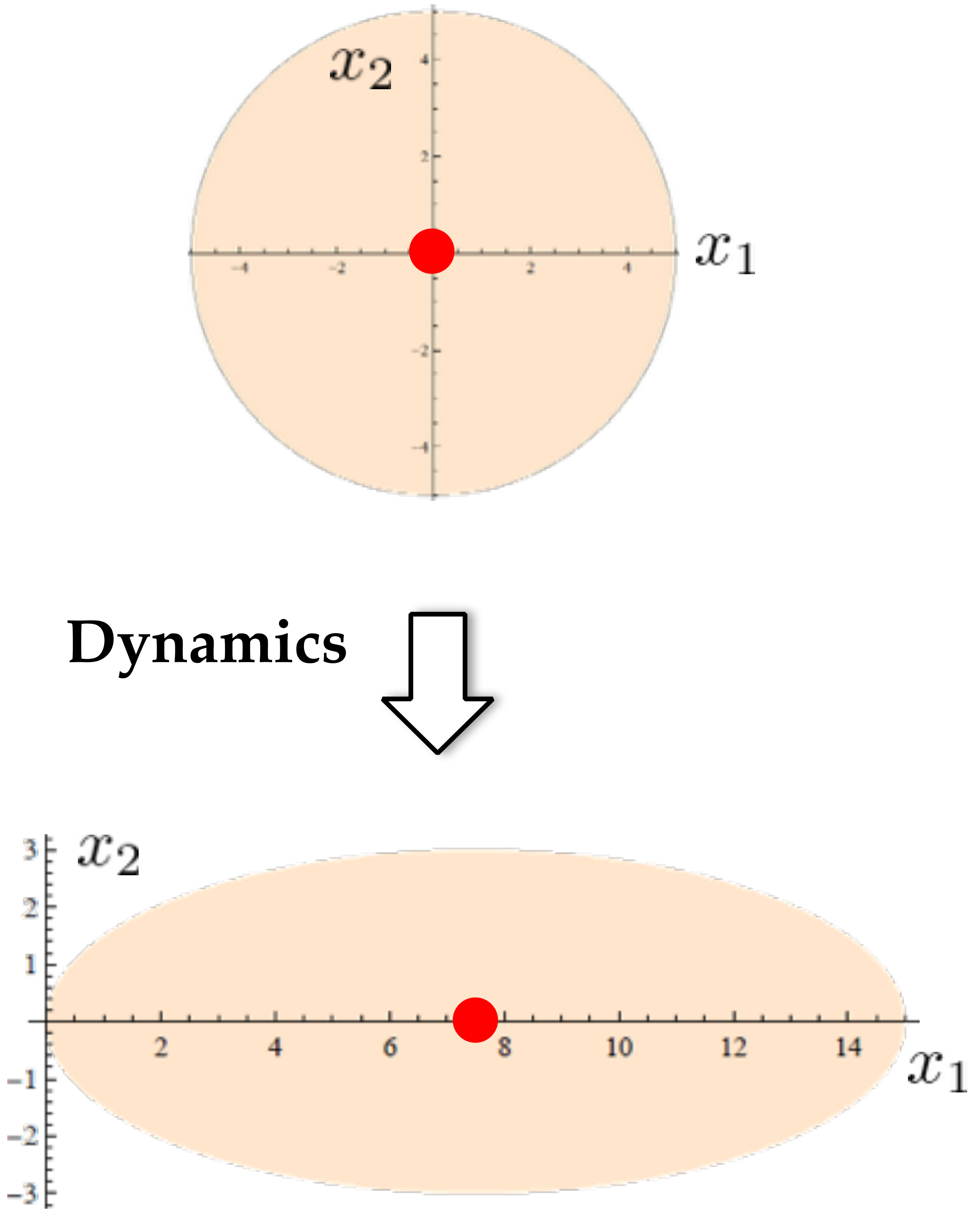
Gale Crater (4.49S, 137.42E)

Uncertainty prediction: joint probability density functions (PDFs)

Nonlinear Dynamics with Monte Carlo on Samples

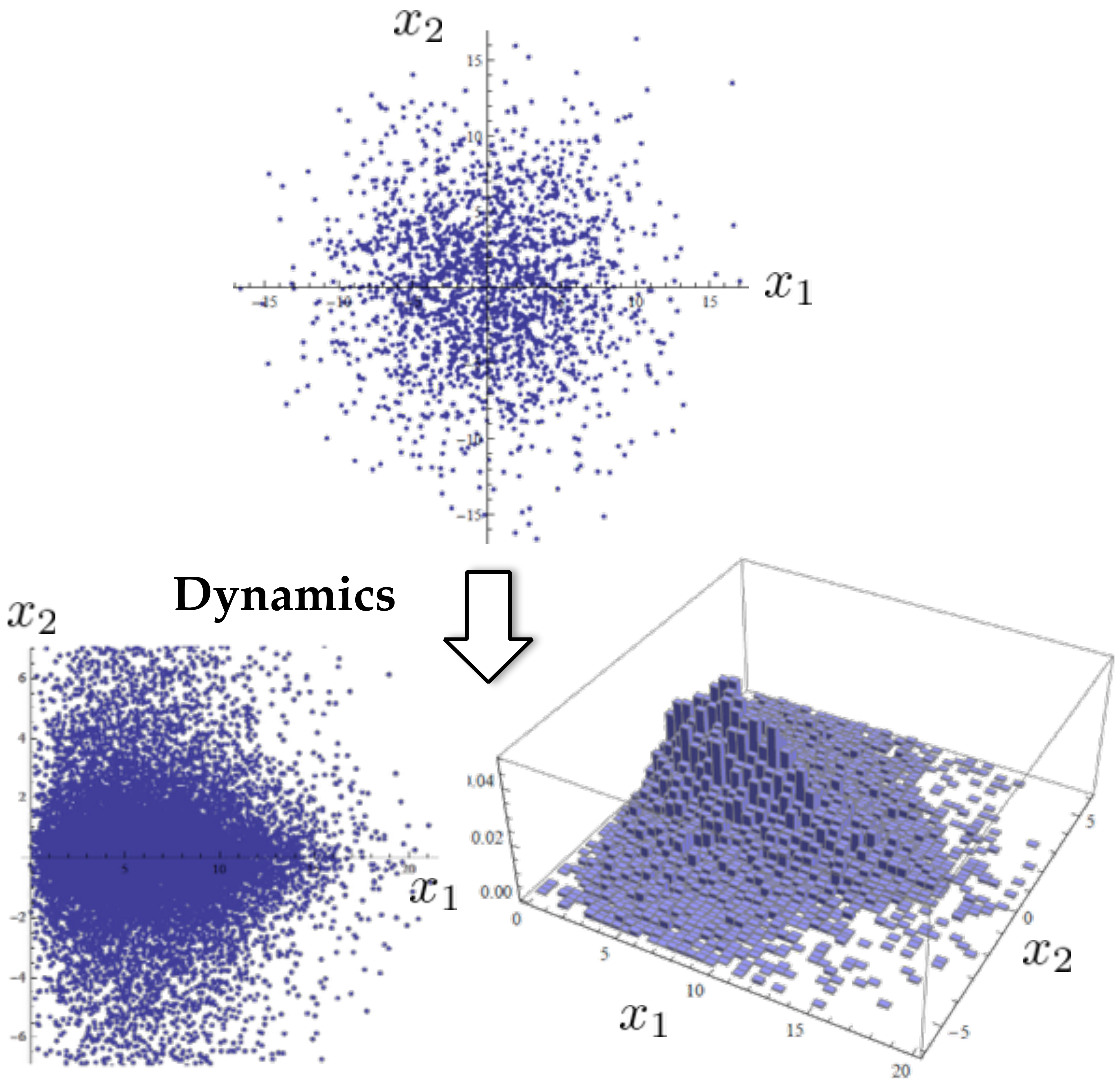


Linear Dynamics with Gaussian Uncertainty



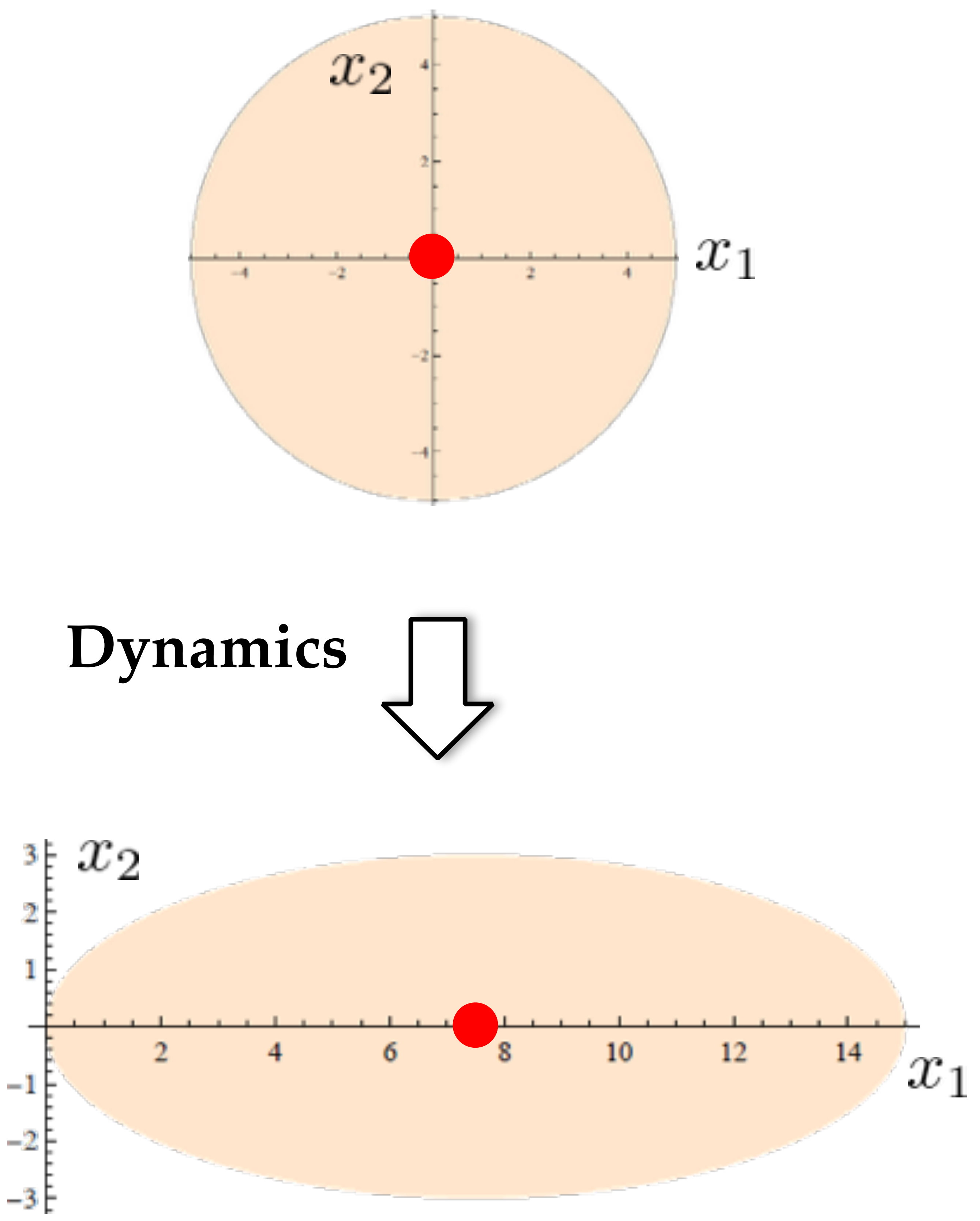
Uncertainty prediction: joint probability density functions (PDFs)

Nonlinear Dynamics with Monte Carlo on Samples



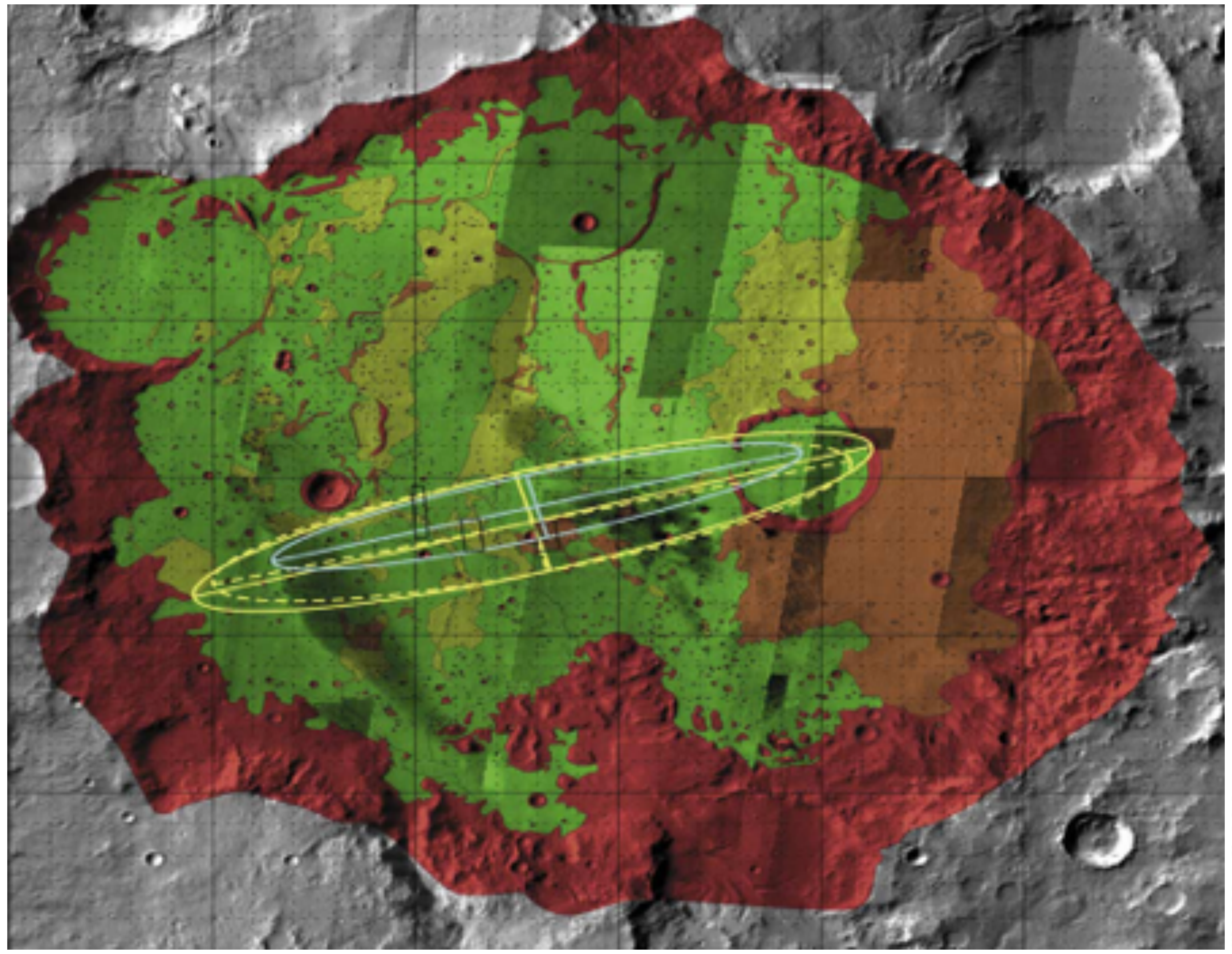
Too expensive for EDL simulation

Linear Dynamics with Gaussian Uncertainty

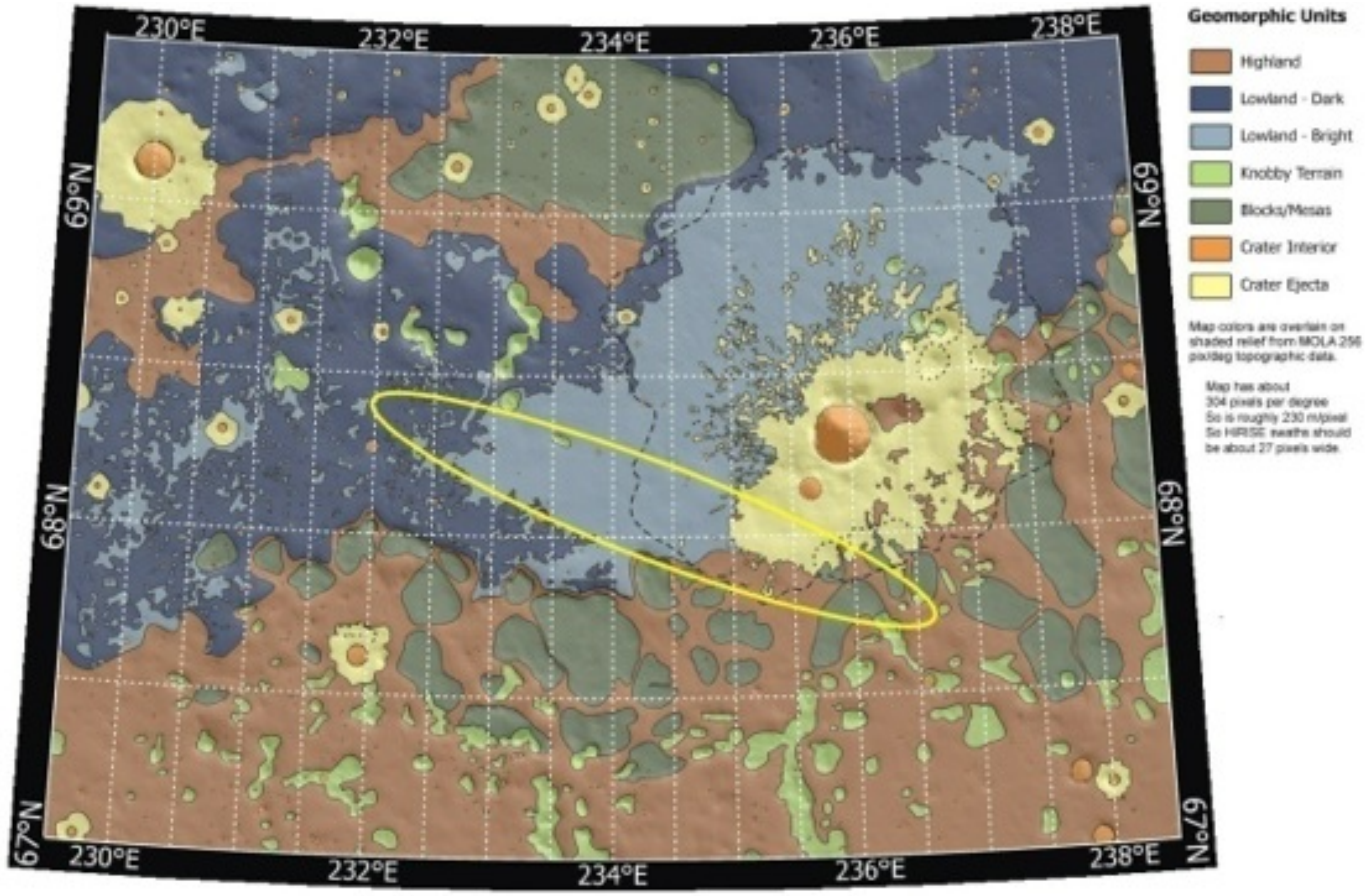


Too ideal for EDL simulation

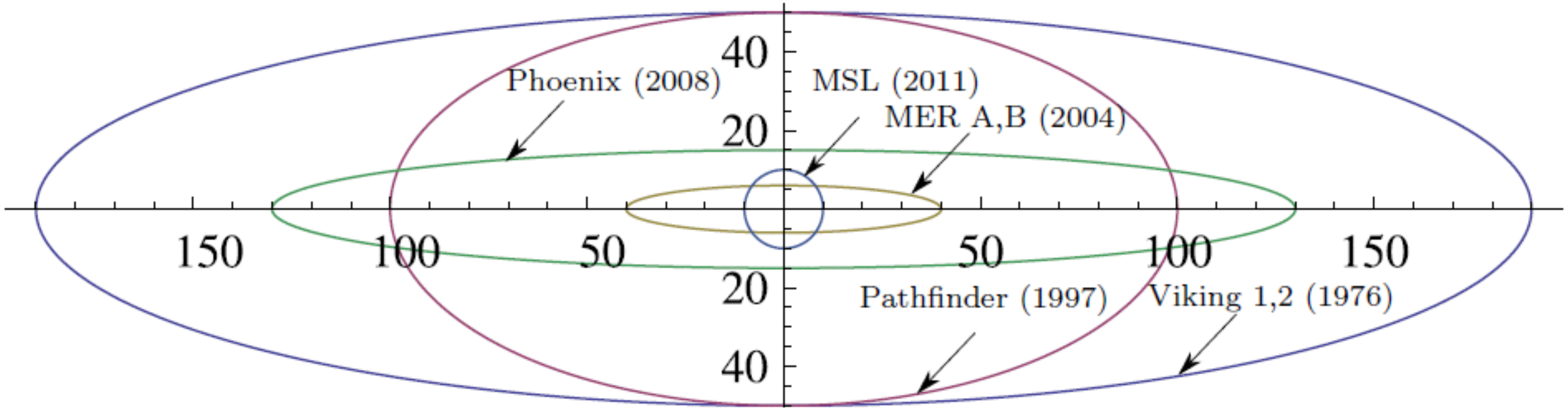
Uncertainty prediction: how bad is the Gaussian fit



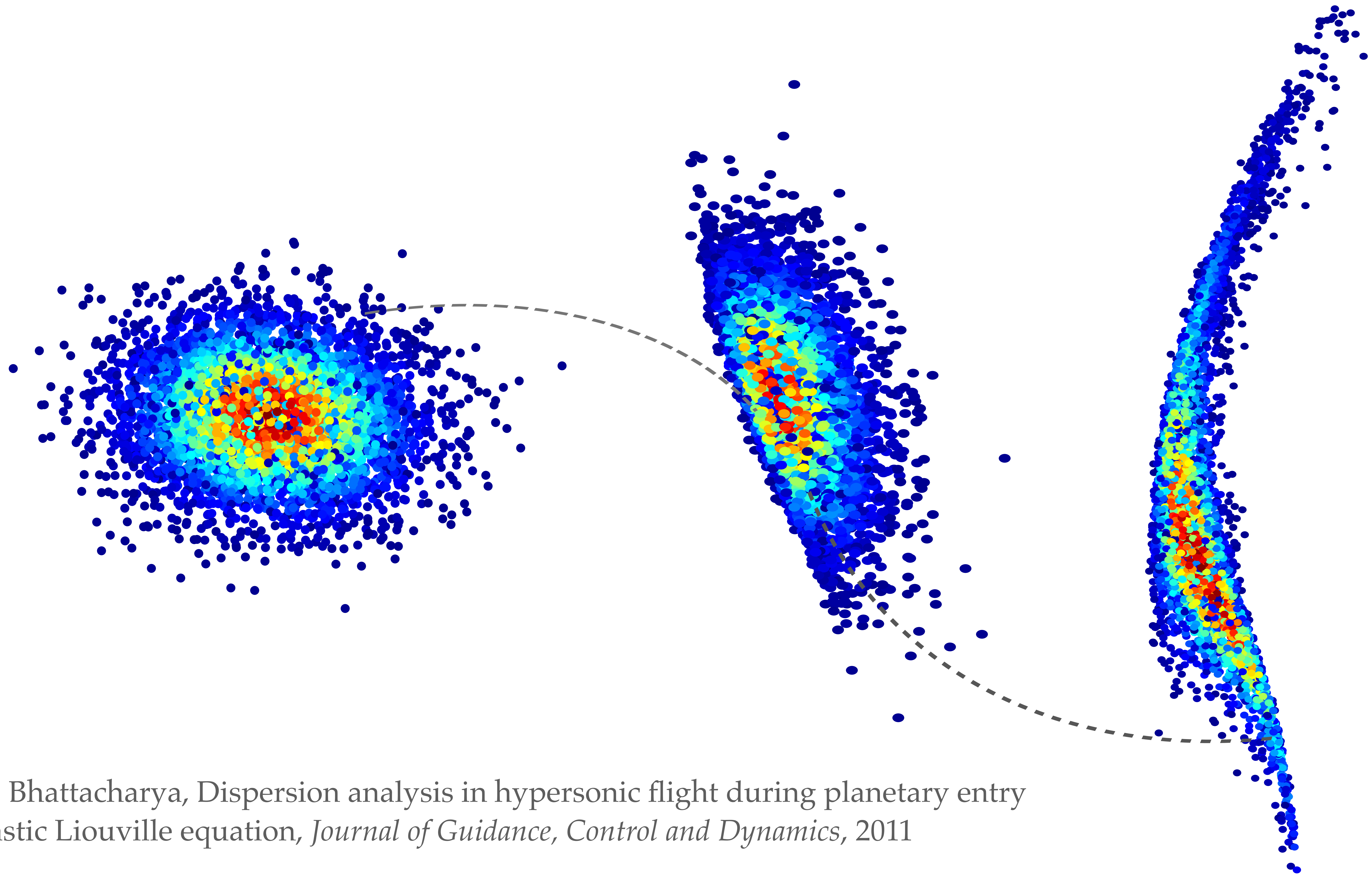
Source: Golombek et. al., J. Geophys. Research. 2003



Credit: NASA JPL, Univ. Washington, St. Louis, JHU APL, Univ. Arizona.



Uncertainty prediction: a new nonparametric method

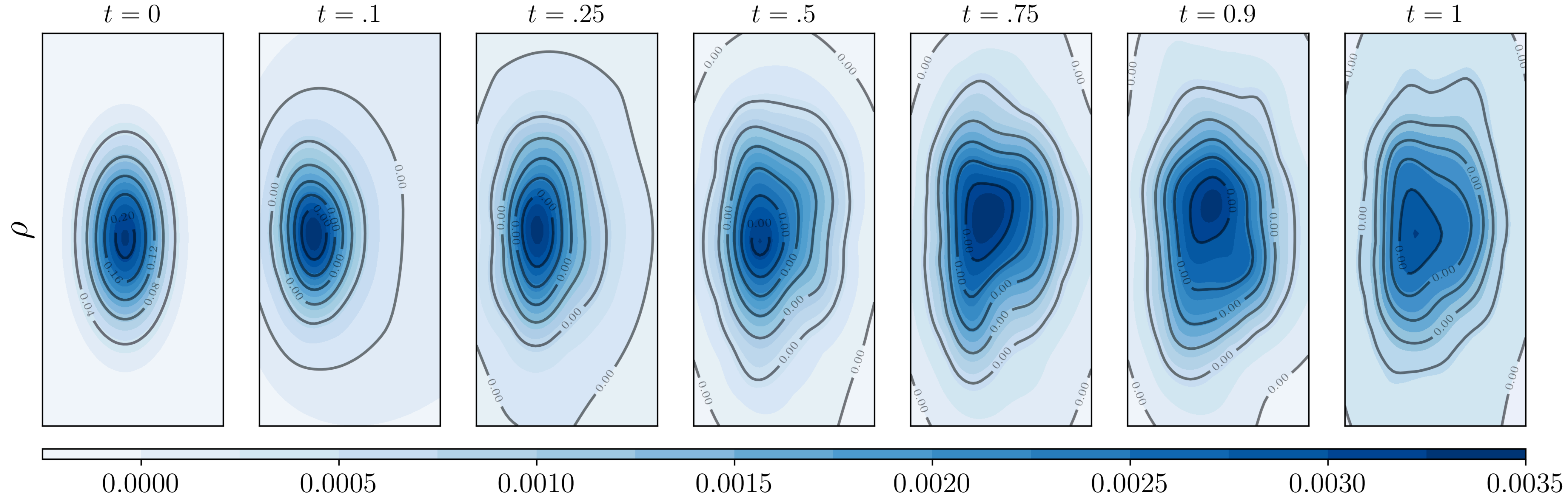


A.H., and R. Bhattacharya, Dispersion analysis in hypersonic flight during planetary entry using stochastic Liouville equation, *Journal of Guidance, Control and Dynamics*, 2011

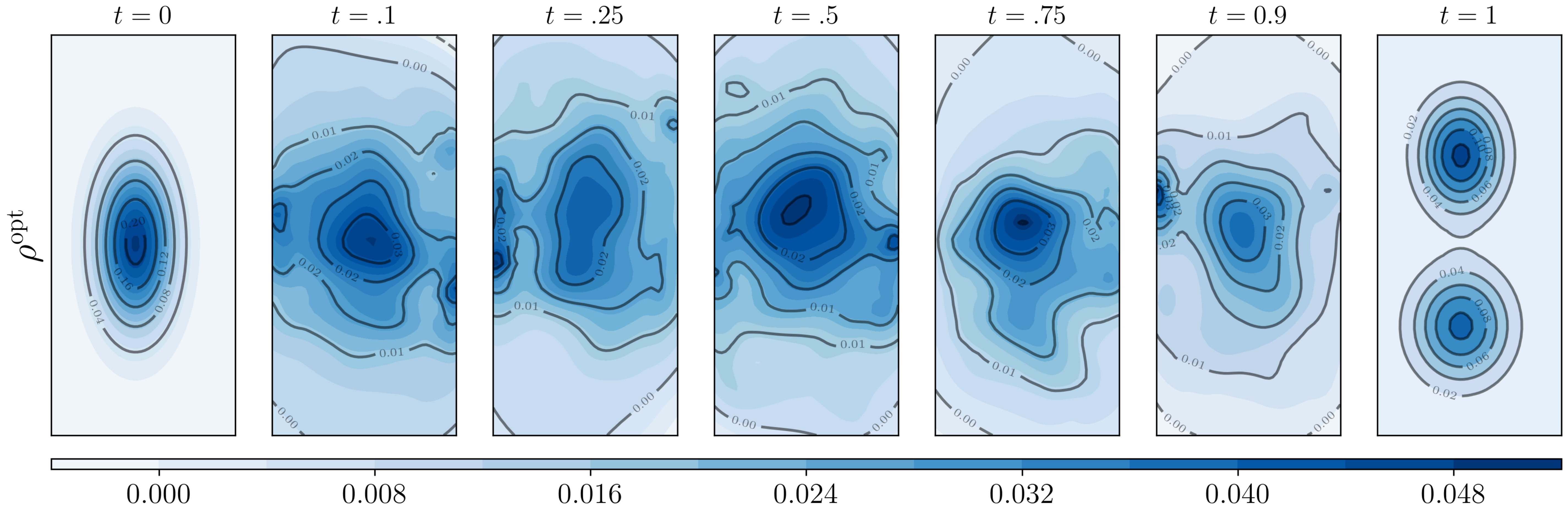
A.H., and R. Bhattacharya, Beyond Monte Carlo: a computational framework for uncertainty propagation in planetary entry, descent and landing, *AIAA GNC*, 2010

Uncertainty control: an emerging direction in control research

Uncontrolled joint PDF evolution:



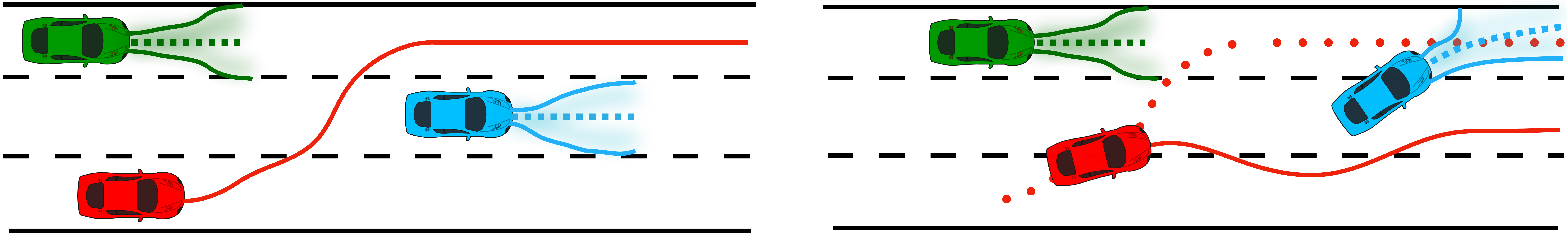
Optimal controlled joint PDF evolution:



K.F. Caluya, and **A.H.**, Wasserstein proximal algorithms for the Schroedinger bridge problem: density control with nonlinear drift, *IEEE Transactions on Automatic Control*, 2021

Uncertainty control: an emerging direction in control research

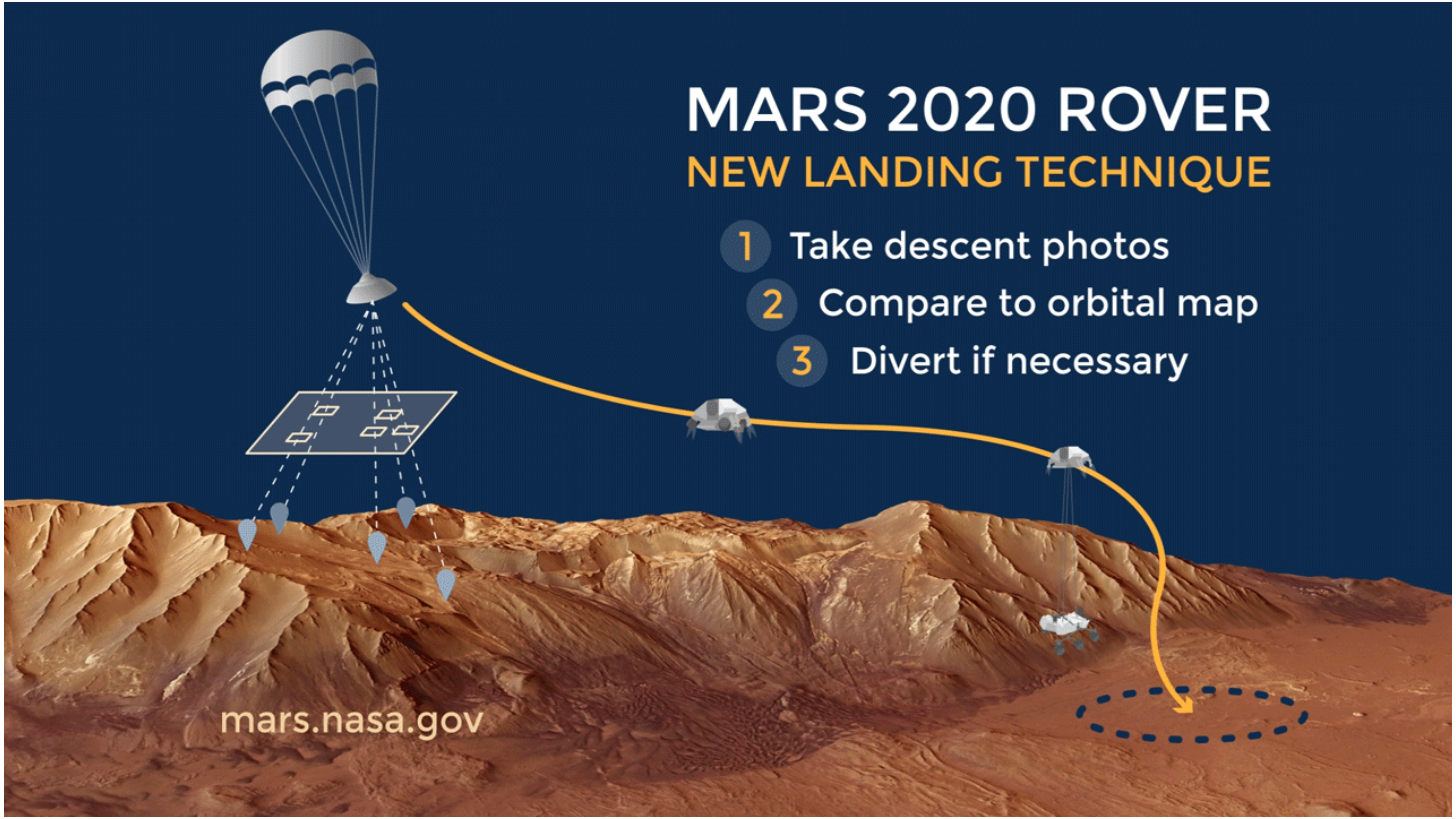
has applications in Earth too



Risk management for safe automated driving in multi-lane highways

S. Haddad, K.F. Caluya, **A.H.**, and B. Singh, Prediction and optimal feedback steering of probability density functions for safe automated driving, *IEEE Control Systems Letters*, 2020

Terrain relative navigation: 2021 landing



Credit: NASA

Summary

Uncertainties are unavoidable in Mars EDL

Feedback control enables high performance EDL in the presence of uncertainties

Will see more advanced control algorithms for future high payload missions

Beyond Mars: many more challenges — landing in Titan, Europa, Enceladus

Thank You

Support: NSF CITRIS PEOPLE AND ROBOTS Ford