

# Scale-Invariant Phenomena in Plasma

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**EGY** plasma



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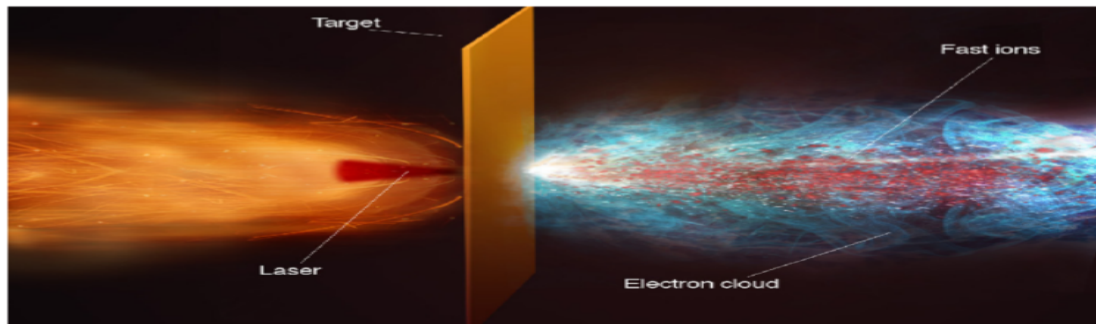
## Multispecies plasma expansion into vacuum: The role of secondary ions and suprathermal electrons

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(a)

## Surface nanocratering by localized plasma expansion induced by slow highly charged ions

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SURFACE NANOCRATERING BY LOCALIZED PLASMA ...

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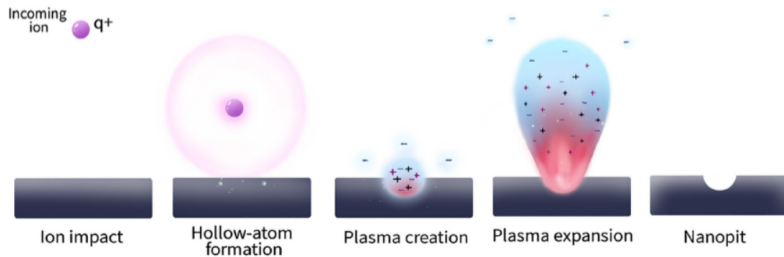


FIG. 2. Schematic diagram for the scenario of nanopit formation by localized plasma expansion.

## Ion Escape Dynamics in the Martian Upper Ionosphere: A Self-Similar Plasma Expansion Approach

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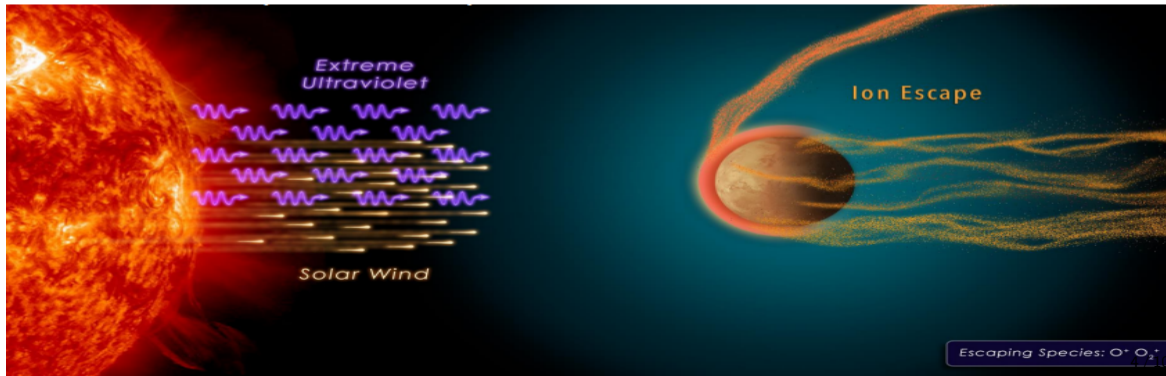
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## three scales , One pattern

System	Driver	Typical scale	What is measured?
2016 plasma slab	Laser	fs – $\mu\text{m}$	density, velocity, field front
2026 nanoplasma in PMMA	ion beam	ps – nm	pit width, pit depth, aspect ratio
2026 Mars upper ionosphere	solar-wind	hour –km	ion density, ion speed, escape rate

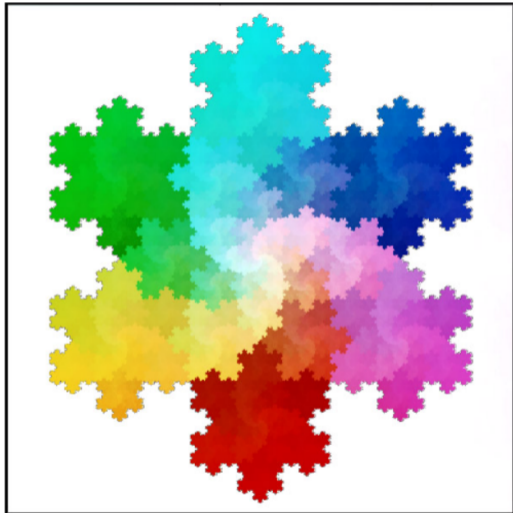
### Unifying statement

The **scale changes**, but the **phenomena is same** .

Source: Scale information summarized from the three uploaded papers.



## Geometry analogy: useful, but not identical



- A fractal repeats a geometric pattern across scales.
- Plasma expansion repeats a **dynamical profile** across scales or times.
- So the analogy helps intuition, but the objects are different:
  - fractal self-similarity = geometry,
  - plasma self-similarity = evolution law.

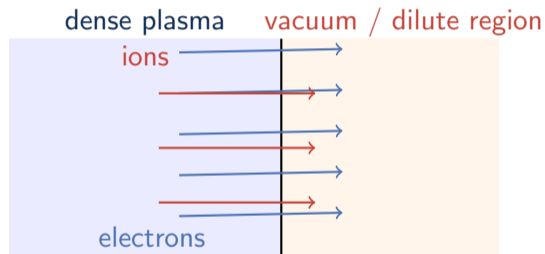
Source: Public-domain Koch snowflake image from Wikimedia Commons, used only as an analogy for scale invariance.





## Physical intuition: expansion into vacuum

- Suppose dense plasma sits next to a low-density region or vacuum.
- Electrons move more easily than ions.
- This creates an ambipolar electric field.
- The field pulls ions outward and a rarefaction region forms.



## Scale invariant – Scale symmetry

### Idea

A phenomenon is **scale invariant** if its shape or governing law stays the same under a suitable change of scale.

### Question

If I zoom out in space and also wait proportionally longer in time, can the plasma look the same?

- If yes, then the solution should not depend on  $x$  and  $t$  independently.
- Then profiles at different times look like **stretched versions of one master curve**.
- It should depend on a **combination** of them that stays unchanged under the scaling.
- That combination is the **similarity variable**.

$$f(x, t) \rightarrow f(\xi)$$

Same shape  $\Rightarrow$  one reduced variable



# Take-home message and key references

## Take-home message

From a laser-produced plasma, to a nanoplasma crater, to escaping ions above Mars, the same idea appears again and again:

$$\text{self-similar expansion} \implies \xi = \frac{x}{c_s t}.$$

The scale changes. The symmetry idea survives.

## Key references used in this seminar

- I. S. Elkamash and I. Kourakis, *Multispecies plasma expansion into vacuum*, Phys. Rev. E 94, 053202 (2016).
- I. S. Elkamash et al., *Surface nanocratering by localized plasma expansion*, Phys. Rev. E 113, 035502 (2026).
- A. Gamal et al., *Ion Escape Dynamics in the Martian Upper Ionosphere*, MNRAS preprint (2026).

Thank you

