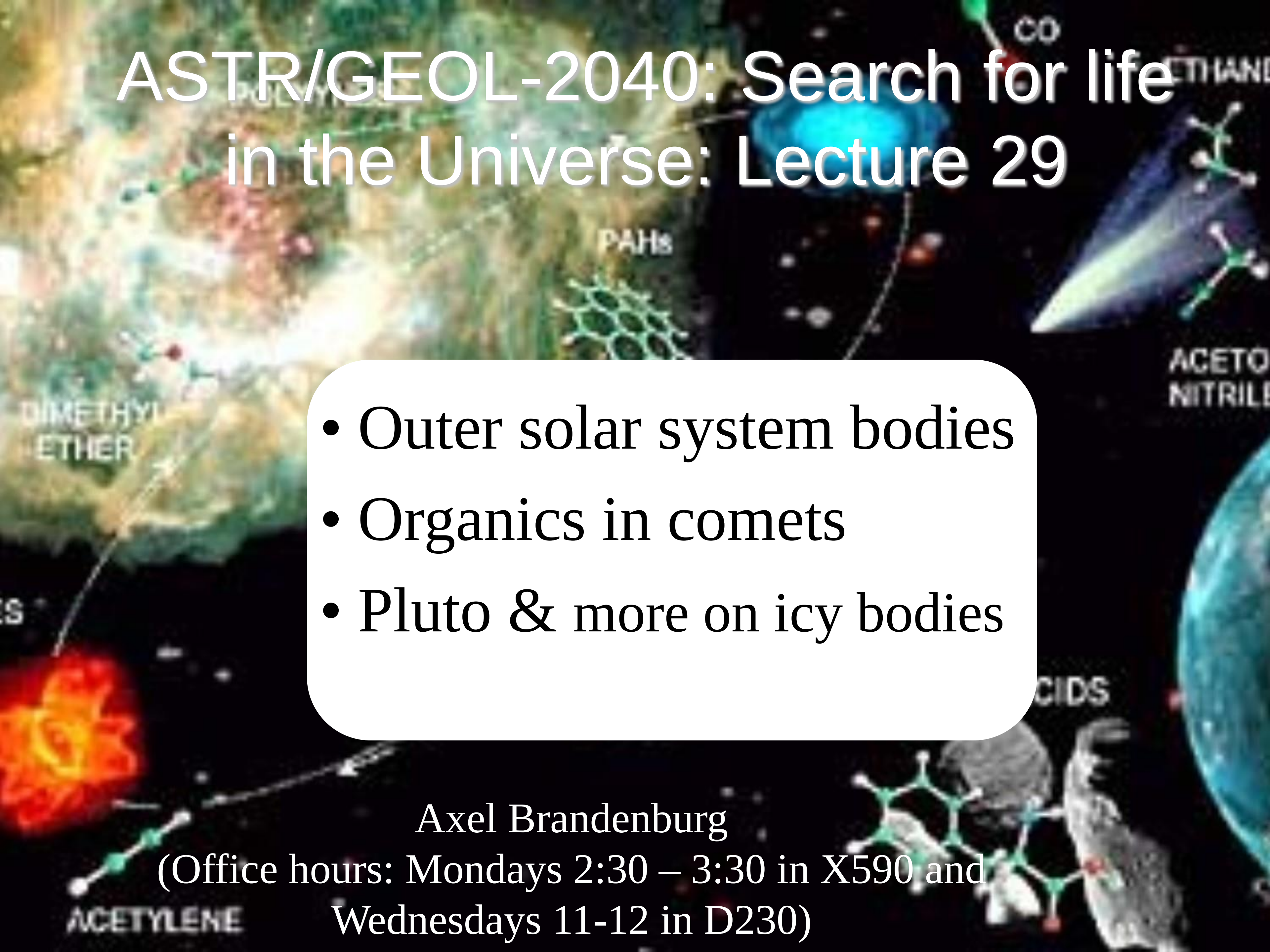
# ASTR/GEOL-2040: Search for life in the Universe: Lecture 29

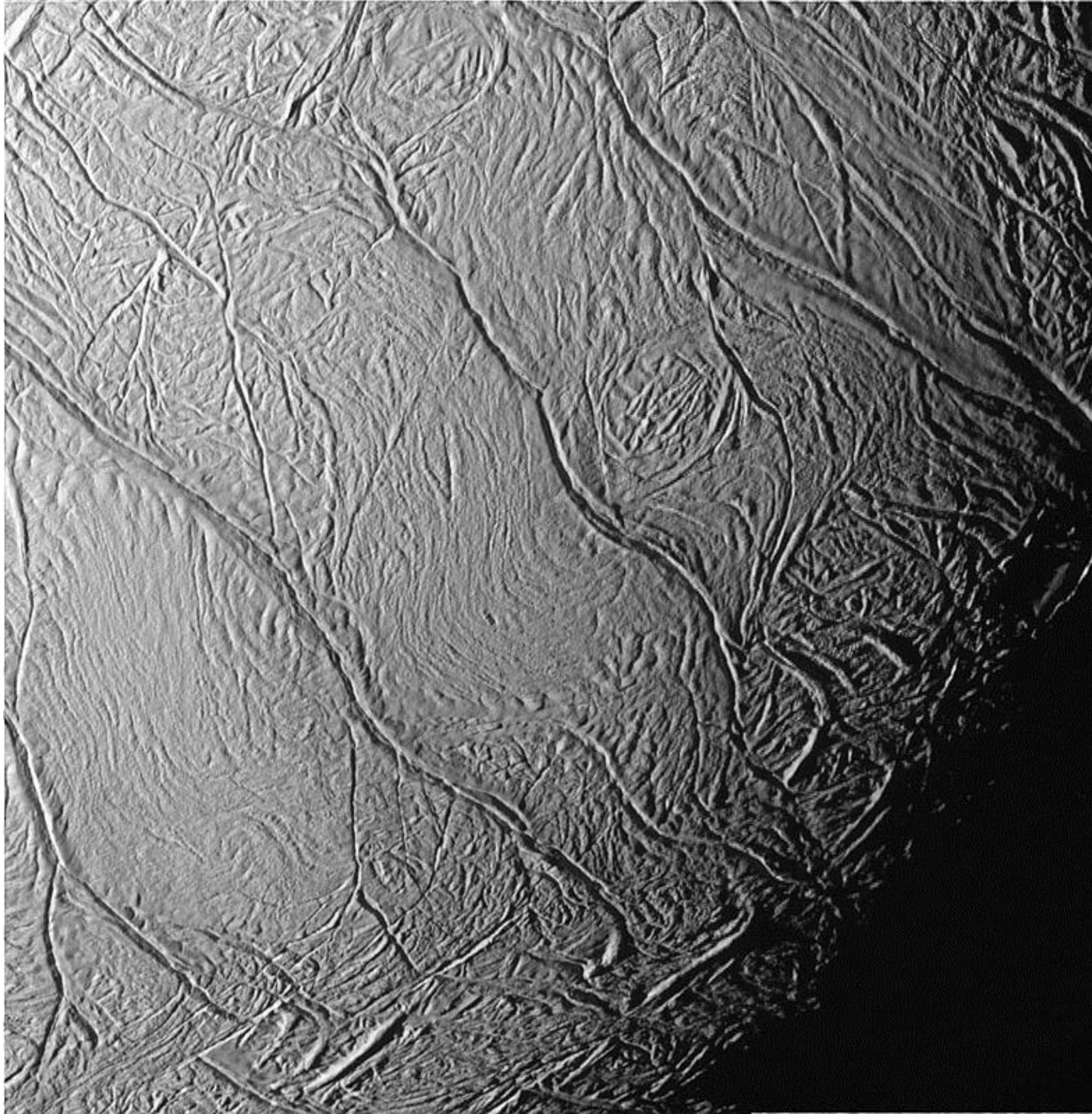
- Outer solar system bodies
- Organics in comets
- Pluto & more on icy bodies

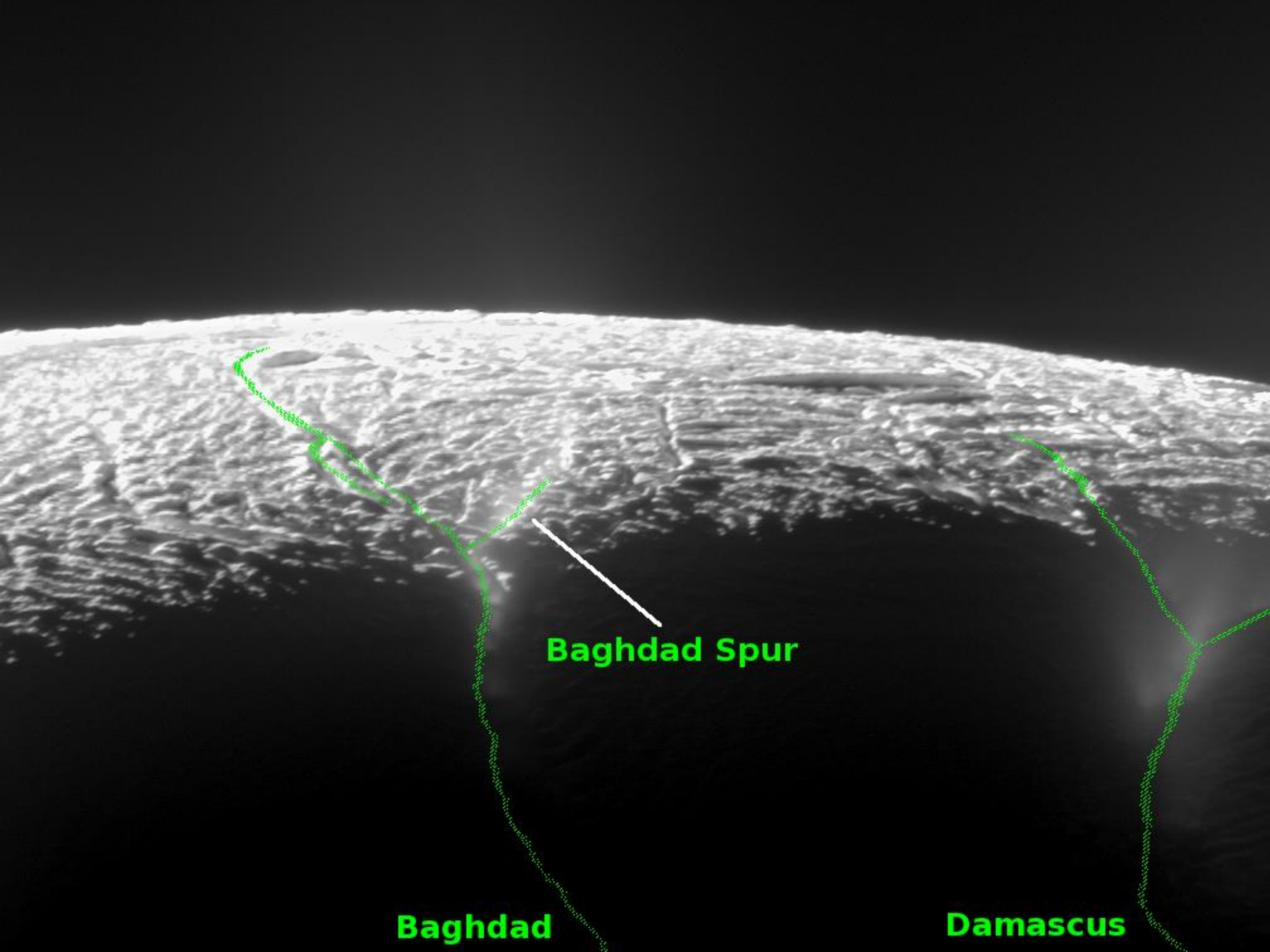
Axel Brandenburg
(Office hours: Mondays 2:30 – 3:30 in X590 and Wednesdays 11-12 in D230)

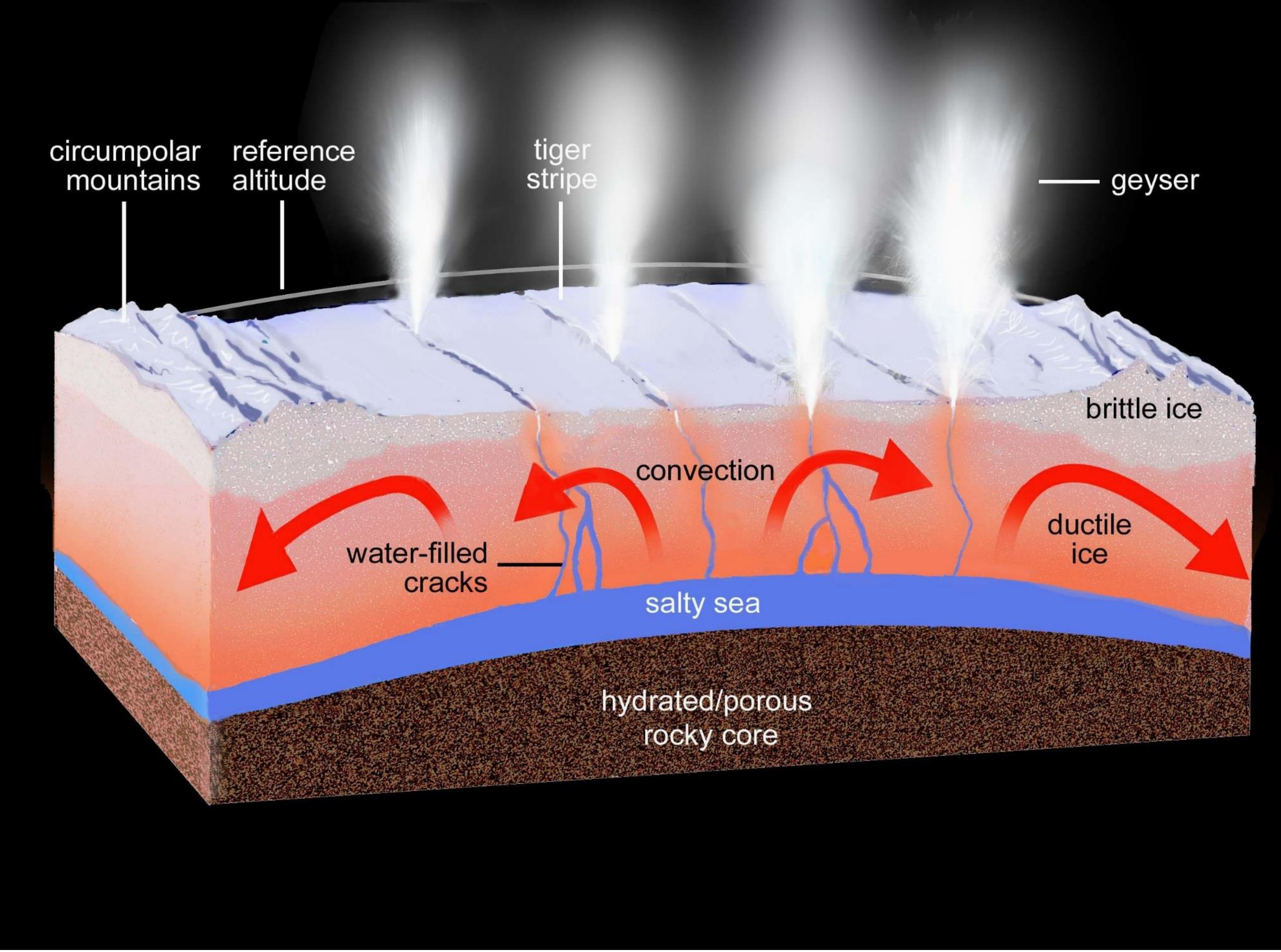


# *Enceladus*

- Damascus
- Bagdad
- Cairo
- Alexandria
- …..




Baghdad Spur
Baghdad
Damascus


circumpolar mountains
reference altitude
tiger stripe
geyser
brittle ice
convection
ductile ice
water-filled cracks
salty sea
hydrated/porous rocky core

# Cassini finds molecular hydrogen in the Enceladus plume: Evidence for hydrothermal processes

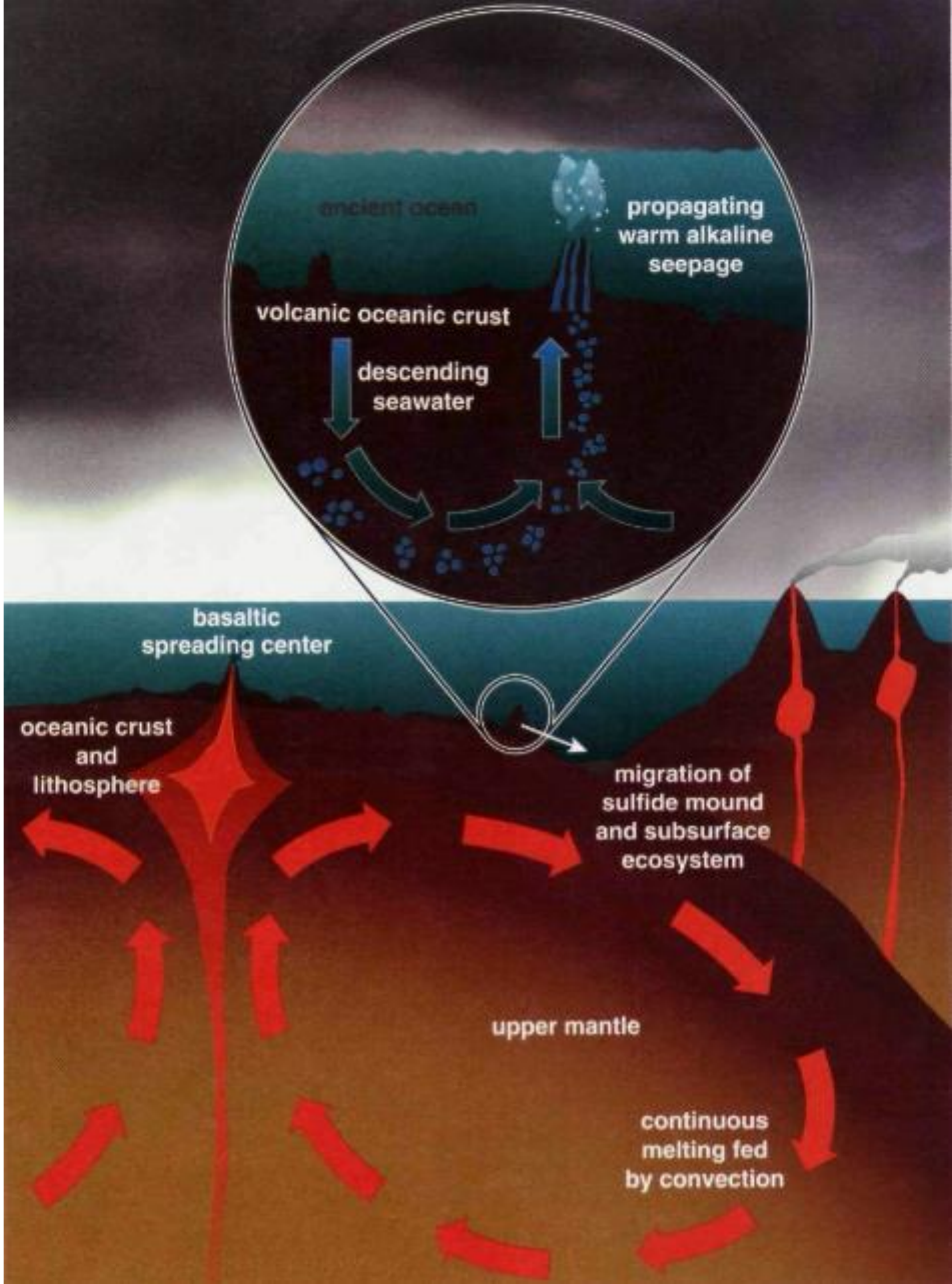
**J. Hunter Waite,[1*] Christopher R. Glein,[1*] Rebecca S. Perryman,[1] Ben D. Teolis,[1] Brian A. Magee,[1] Greg Miller,[1] Jacob Grimes,[1] Mark E. Perry,[2] Kelly E. Miller,[1] Alexis Bouquet,[1] Jonathan I. Lunine,[3] Tim Brockwell,[1] Scott J. Bolton[1]**

Saturn's moon Enceladus has an ice-covered ocean; a plume of material erupts from cracks in the ice. The plume contains chemical signatures of water-rock interaction between the ocean and a rocky core. We used the Ion Neutral Mass Spectrometer onboard the Cassini spacecraft to detect molecular hydrogen in the plume. By using the instrument's open-source mode, background processes of hydrogen production in the instrument were minimized and quantified, enabling the identification of a statistically significant signal of hydrogen native to Enceladus. We find that the most plausible source of this hydrogen is ongoing hydrothermal reactions of rock containing reduced minerals and organic materials. The relatively high hydrogen abundance in the plume signals thermodynamic disequilibrium that favors the formation of methane from $CO_2$ in Enceladus' ocean.

Waite *et al.*, *Science* **356**, 155–159 (2017) 14 April 2017

# *Hydrothermal vents*

- Black smokers
  - Short-lived
  - Acidic, pH 3-5
  - $CO_2$, $H_2S$
- Alkaline vents
  - Long-lived (x10)
  - Lost City
  - $H_2$, $CH_4$, ...



# *What kind of evidence to expect?*

A. Silicates in the plumes
B. Iron compounds in the plumes
C. Hydrogen is enough
D. Carbon dioxide
E. Methane

# *Reduction of water*

Purely geological process

$$\overset{\text{Fayalite}}{3\ Fe_2SiO_4} + \overset{\text{water}}{2\ H_2O} \rightarrow \overset{\text{magnetite}}{2\ Fe_3O_4} + \overset{\text{aqueous silica}}{3\ SiO_2} + \overset{\text{hydrogen}}{2\ H_2}$$

# *What kind of evidence to expect?*

A. Silicates in the plumes
B. Iron compounds in the plumes
C. Hydrogen is enough
D. Carbon dioxide
E. Methane

# *Quantitative findings*

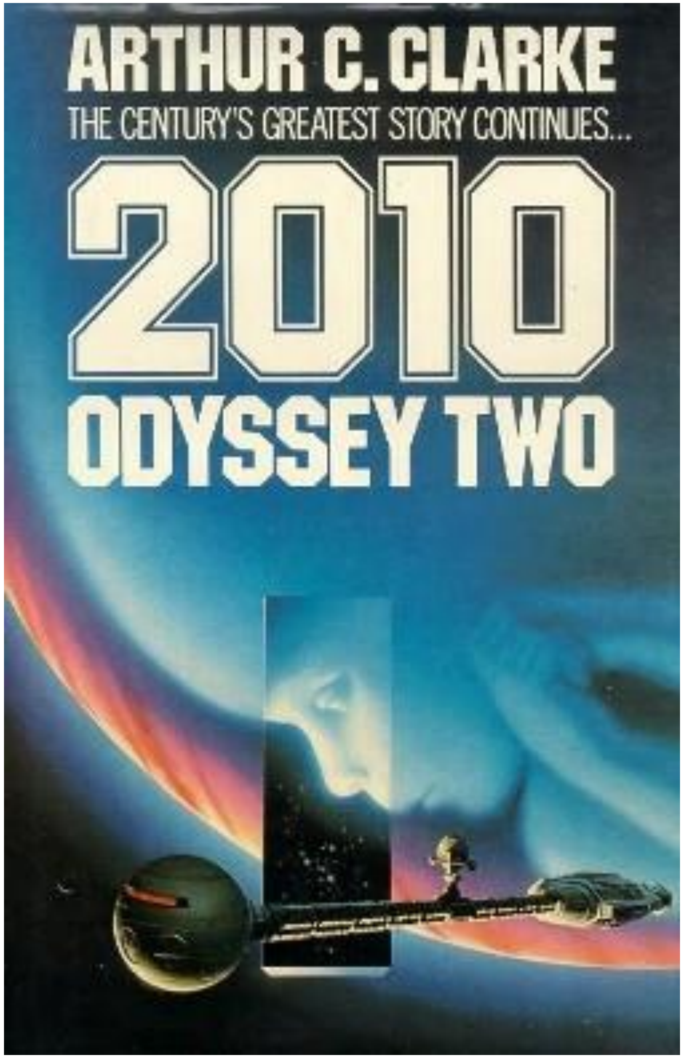
**Table 1. The major species composition of Enceladus' plume gas.** Volume mixing ratios are derived from Cassini INMS measurements [(*20*), sections 2.4 and 3.2].

| Constituent | Mixing ratio (%) |
|---|---|
| $H_2O$ | 96 to 99 |
| $CO_2$ | 0.3 to 0.8 |
| $CH_4$ | 0.1 to 0.3 |
| $NH_3$ | 0.4 to 1.3 |
| $H_2$ | 0.4 to 1.4 |

- During "E21" fly-by, Cassini: over tiger stipes
- Modulation of $H_2$
- Too much for clathrates
- If $H_2$ were stored, there would be more $CH_4$ given the $CO_2$ amount
- $4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$

# *Who thought first of life on Europa?*

- Orbital period: 3.551 d
- Slight eccentricity
  - because of resonant orbit
- Europa's shape changes: elongated → spherical
- Arthur C. Clarke: thought about it in 1982
- PDF file on internet!



# *Europa: reducing ocean*

- Hydrothermal systems: $H_2$, $CH_2$, Fe(II)
- → sink for oxygen
- Free oxygen in ocean depends on balance
- Peroxide delivery $10^9$ → $10^8$ moles
- Our ocean $3 \times 10^9$ moles
  - Photosynthesis…
- Europa's ocean anoxic
- Details in Longstaff's book, p.318

# *Peroxide biology*

- Peroxide half-life 10 yr
- Formaldehyde HCHO as C source
  - $HCHO + O_2 \rightarrow H_2O + CO_2$

  - A. chemoorganoautotroph
  - B. chemoorganoheterotroph
  - C. chemolithoautotroph
  - D. chemolithoheterotroph

# *Peroxide biology*

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- Formaldehyde HCHO as C source
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  - D. chemolithoheterotroph

# Peroxide biology in Europa's ocean?

- Just as *hyphomicrobium*
- Limited by C and energy
- ocean could support $10^{23}$ prokaryotes (Europa)
  - Remarkable given poor nutrient+energy supply
- Earth: $5 \times 10^{30}$ prokaryotes

# EUROPA AS AN ABODE OF LIFE

*Invited Paper*

CHRISTOPHER F. CHYBA[1,2] and CYNTHIA B. PHILLIPS[1]
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(Received 17 April 2001; accepted in revised form 3 August 2001)

**Abstract.** Life as we know it on Earth depends on liquid water, a suite of 'biogenic' elements (most famously carbon) and a useful source of free energy. Here we review Europa's suitability for life from the perspective of these three requirements. It is likely, though not yet certain, that Europa harbors a subsurface ocean of liquid water whose volume is about twice that of Earth's oceans. Little is known about Europa's inventory of carbon, nitrogen, and other biogenic elements, but lower bounds on these can be placed by considering the role of cometary delivery over Europa's history. Sources of free energy are challenging for a world covered with an ice layer kilometers thick, but it is possible that hydrothermal activity and/or organics and oxidants provided by the action of radiation chemistry at Europa's surface and subsequent mixing into Europa's ocean could provide the electron donors and acceptors needed to power a Europan ecosystem. It is not premature to draw lessons from the search for life on Mars with the Viking spacecraft for planning exobiological missions to Europa.

**Keywords:** astrobiology, Europa, exobiology, Jupiter, oceans, radiation

*Origins of Life and Evolution of the Biosphere* **32:** 47–68, 2002.
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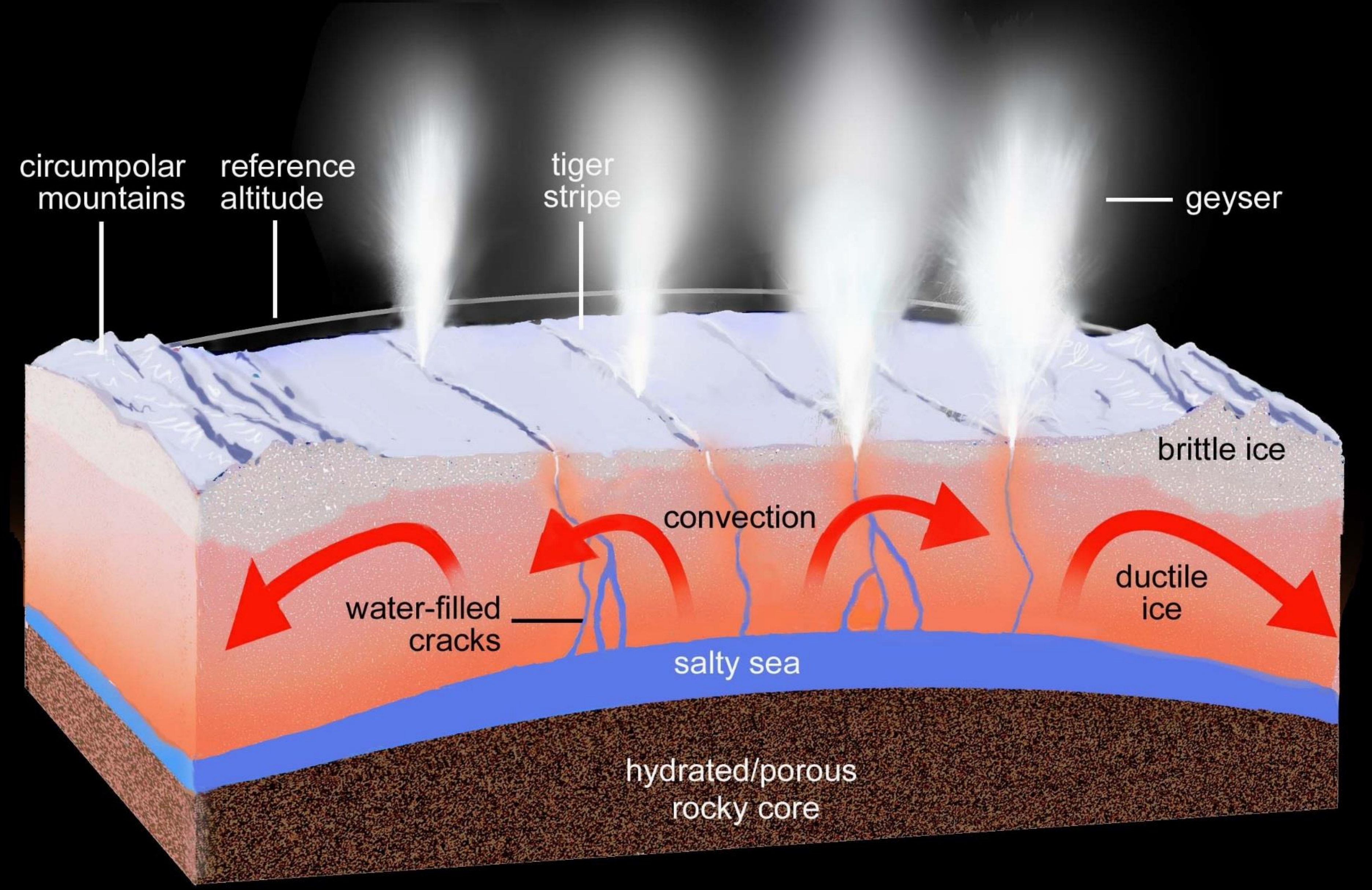
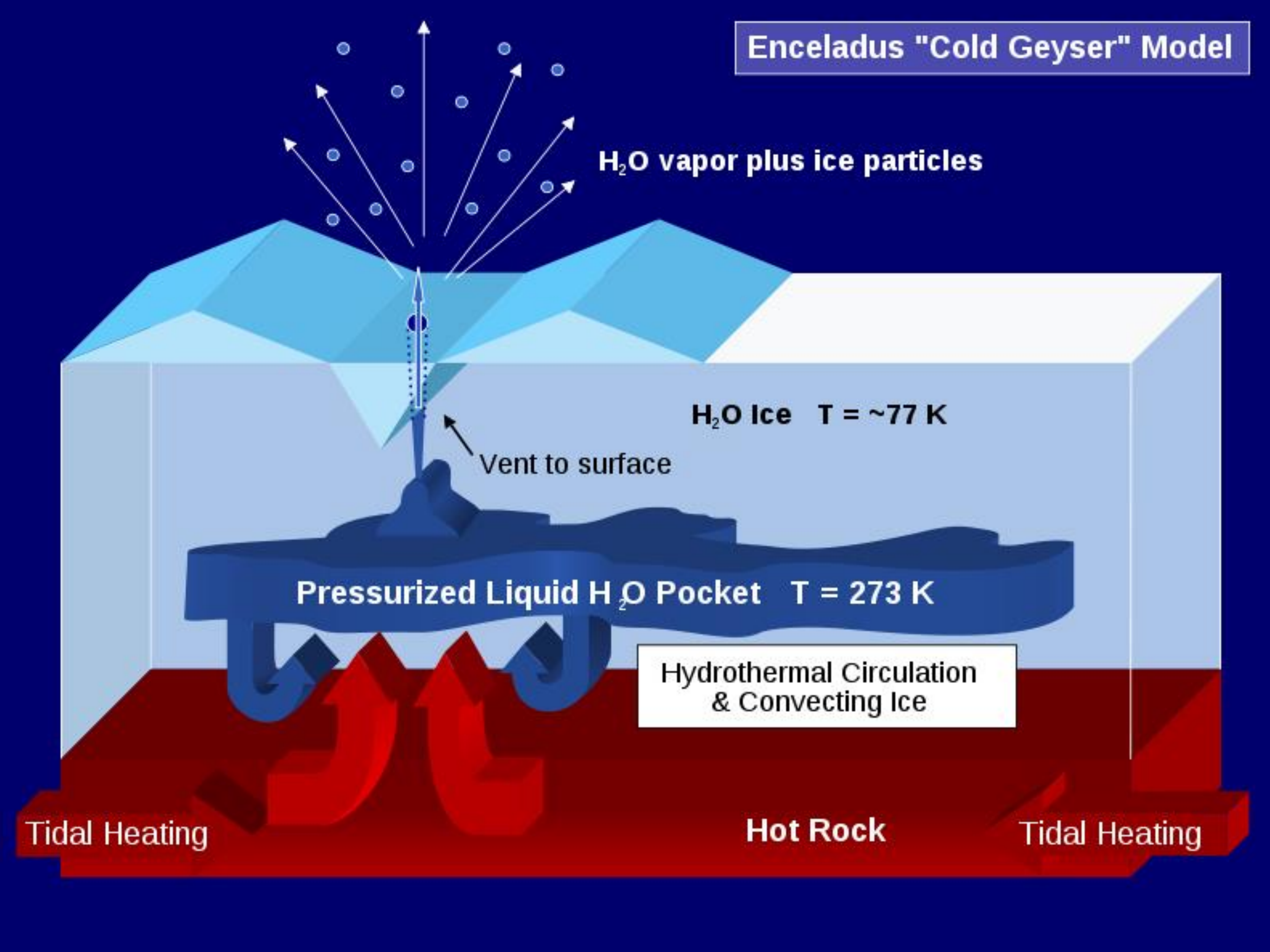

circumpolar mountains
reference altitude
tiger stripe
geyser
brittle ice
convection
ductile ice
water-filled cracks
salty sea
hydrated/porous rocky core


Enceladus "Cold Geyser" Model
$H_2O$ vapor plus ice particles
$H_2O$ Ice T = ~77 K
Vent to surface
Pressurized Liquid $H_2O$ Pocket T = 273 K
Hydrothermal Circulation & Convecting Ice
Tidal Heating
Hot Rock
Tidal Heating

# Delivery of prebiotic molecules

# Astrobiological relevance

Editorial Open Access

## Trends in Astrobiology – Comets, Pluto and beyond

**Chandra Wickramasinghe N**[1,2,3]

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[2]*Institute for the Study of Panspermia and Astroeconomics, Gifu, Japan*

[3]*University of Peradeniya, Peradeniya, Sri Lanka*

***Corresponding author:** Wickramasinghe NC, Buckingham Centre for Astrobiology (BCAB), Buckingham University, UK, Tel: +44-777-838-9243; E-mail: ncwick@gmail.com

**Rec date:** July 14, 2015; **Acc date:** July 16, 2015; **Pub date:** July 20, 2015

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Influenza viruses and comets

Hoyle, F.; Wickramasinghe, N. C.

AA(University College, PO Box 78, Cardiff CPUXI CPUXL, UK)

Nature, Volume 327, Issue 6124, pp. 664 (1987).

06/1987

# Liquid water in Temple 1?

## Liquid water in comets: implications for astrobiology

J.T. Wickramasinghe, N.C. Wickramasinghe & W.M. Napier

Cardiff Centre for Astrobiology, Cardiff University, 2 North Road, Cardiff CF10 3DY

**ABSTRACT**

We show that radiogenic heating in primordial comets of radii in excess of ~10km could produce liquid water cores persisting for hundreds of thousands to millions of years. Supposing comets were seeded with even the smallest numbers of viable microbes at the time of their formation from pre-solar material, there is ample time for exponential amplification within the liquid interiors before refreezing occurs. Freeze-dried biological material is returned to interplanetary and interstellar space during cometary activity as the outer layers of comets are stripped away via sublimation. Modelling of the post-impact 8-12μm spectra of Tempel 1 gives a strong indication of mixtures of clays and organics in comparable quantity, clays in turn providing evidence of a liquid water history of the comet. The totality of comets in a galaxy or a cluster of galaxies, seems to provide a far more promising setting for an origin of life than any setting thus far proposed in relation to the primitive Earth. Once life has originated in a comet mechanisms of interstellar panspermia that have recently been identified will disperse throughout the Galaxy within a few billion years.

# *Theoretically possible*

- Pressure high enough in its center
- Radius > 6 km

A necessary condition for liquid water to be stable within a comet is that the ambient temperature and pressure exceed the corresponding triple point values, $T$=273K and $p$=6mb. For a static uniform sphere of radius $r$ and density $\rho$ the central pressure is

$$p = \frac{2\pi}{3} G\rho^2 r^2 \tag{1}$$

Assuming $\rho \approx 0.3$ g cm$^{-3}$ and setting $p$>6mb equation (1) yields

$$r > 6\text{km} \tag{2}$$

This is clearly the minimum radius of a cometary body that can sustain a liquid water core. However, the production of a liquid core in an initially frozen comet and its persistence would depend on available energy sources as well as the thermal properties of the constituent material as we shall discuss below.

# Spectral evidence

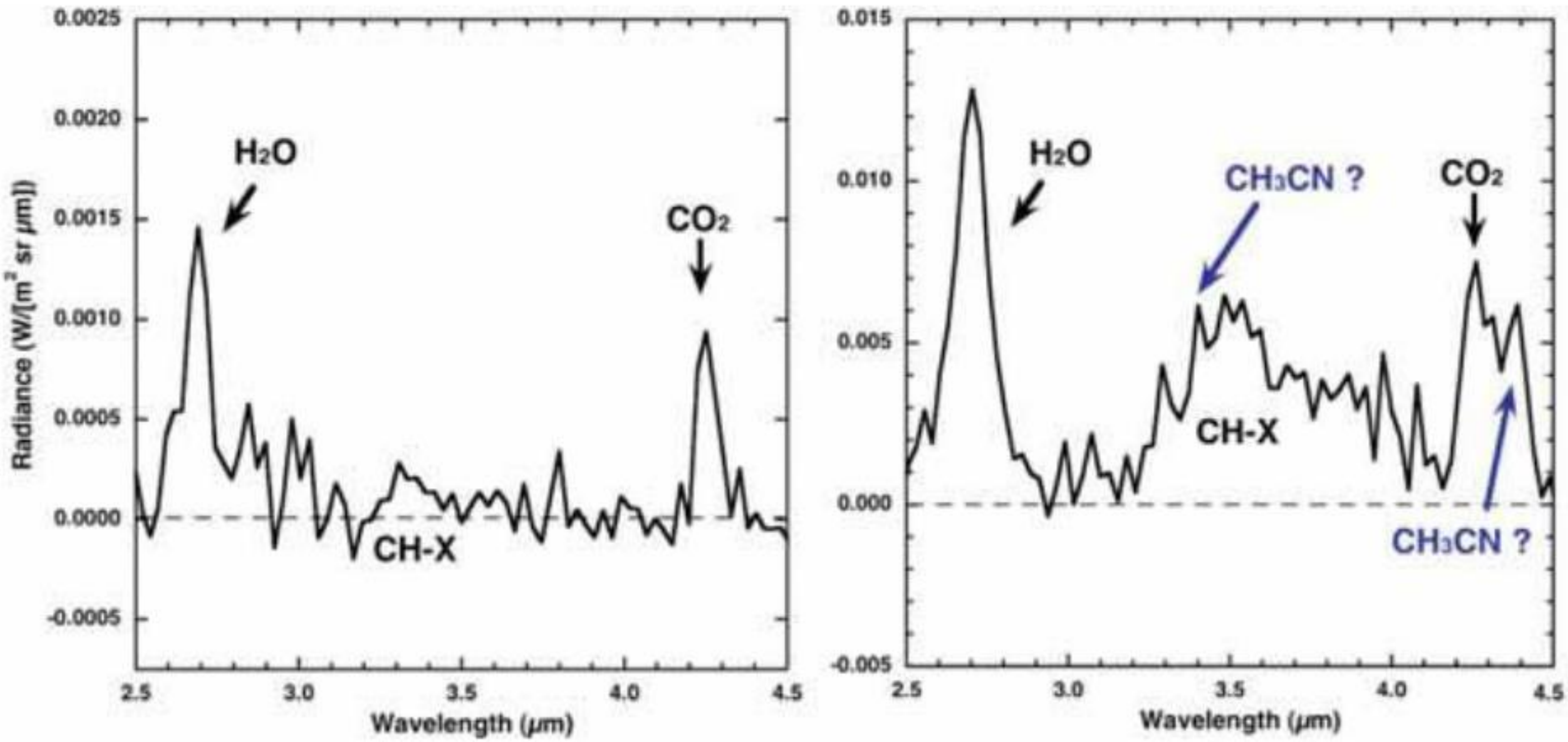


Figure 3: Spectra of coma of Tempel 1. Ten minutes before (left panel) and four minutes after the impact (right panel) on July 4th 2005.

# Red rain: not unusual

## Bloody rain again! Red rain and meteors in history and myth

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**Abstract**: In July 2001, red rain fell over Kerala in India shortly after reports of a meteor. When analysed, this red rain appeared to contain red cells, apparently demonstrating that such cells must exist in space and that the theory of panspermia is correct. However, doubts have been expressed about whether reports of a meteor were merely a coincidence. This paper examines historical and mythical accounts of red rain, to establish if these, too, show a connection with meteors.

*Received 3 April 2007, accepted 13 June 2007*

**Key words**: astrobiology, cometomythology, history, meteors, myth, red rain.

# His conclusion

Although historical reports provide insufficient details to prove that red rain has an extraterrestrial origin, there appears to be a strong link between some reported events and meteoritic activity. The reported airburst just before the fall of red rain in Kerala fits a familiar pattern, and cannot be dismissed so easily as an unrelated coincidence. With that in mind, the Kerala samples, and any others that might occur in the future, should be investigated with every scientific resource at our disposal.

# Original paper

Astrophys Space Sci (2006) 302:175–187
DOI 10.1007/s10509-005-9025-4

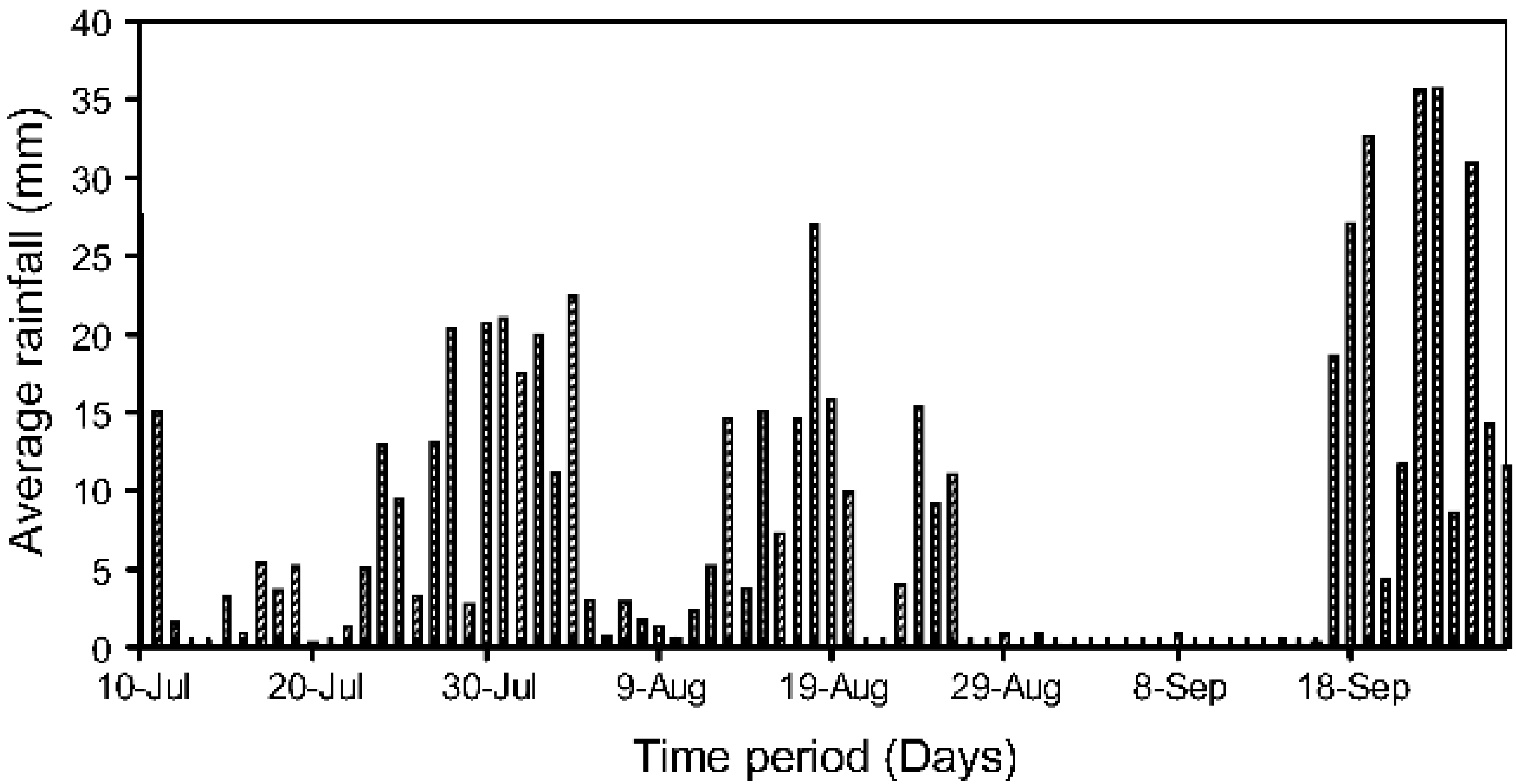
ORIGINAL ARTICLE

## The Red Rain Phenomenon of Kerala and its Possible Extraterrestrial Origin

**Godfrey Louis · A. Santhosh Kumar**

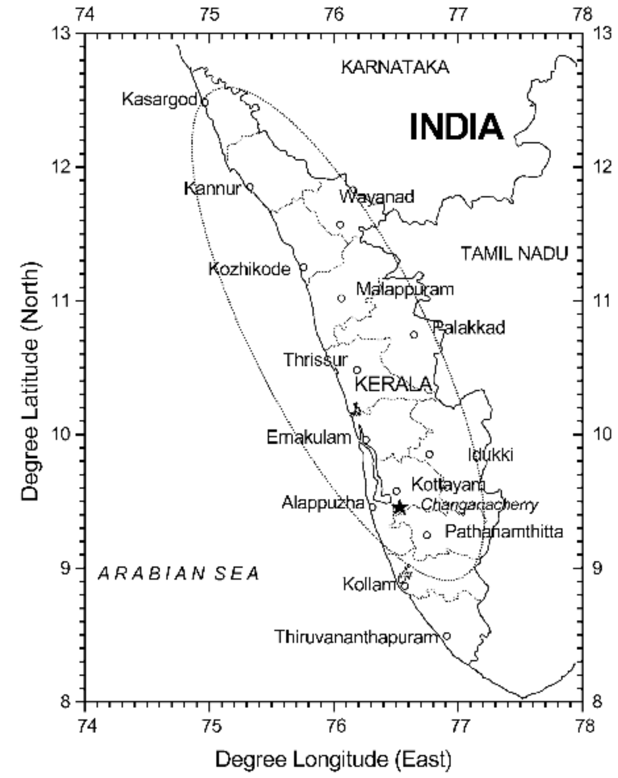
**Abstract** A red rain phenomenon occurred in Kerala, India starting from 25th July 2001, in which the rainwater appeared coloured in various localized places that are spread over a few hundred kilometers in Kerala. Maximum cases were reported

red rain phenomenon first started in Kerala after a meteor airburst event, which occurred on 25th July 2001 near Changanacherry in Kottayam district. This meteor airburst is evidenced by the sonic boom experienced by several people during early morning of that day. The first case of red



# Associated with cometary airburst

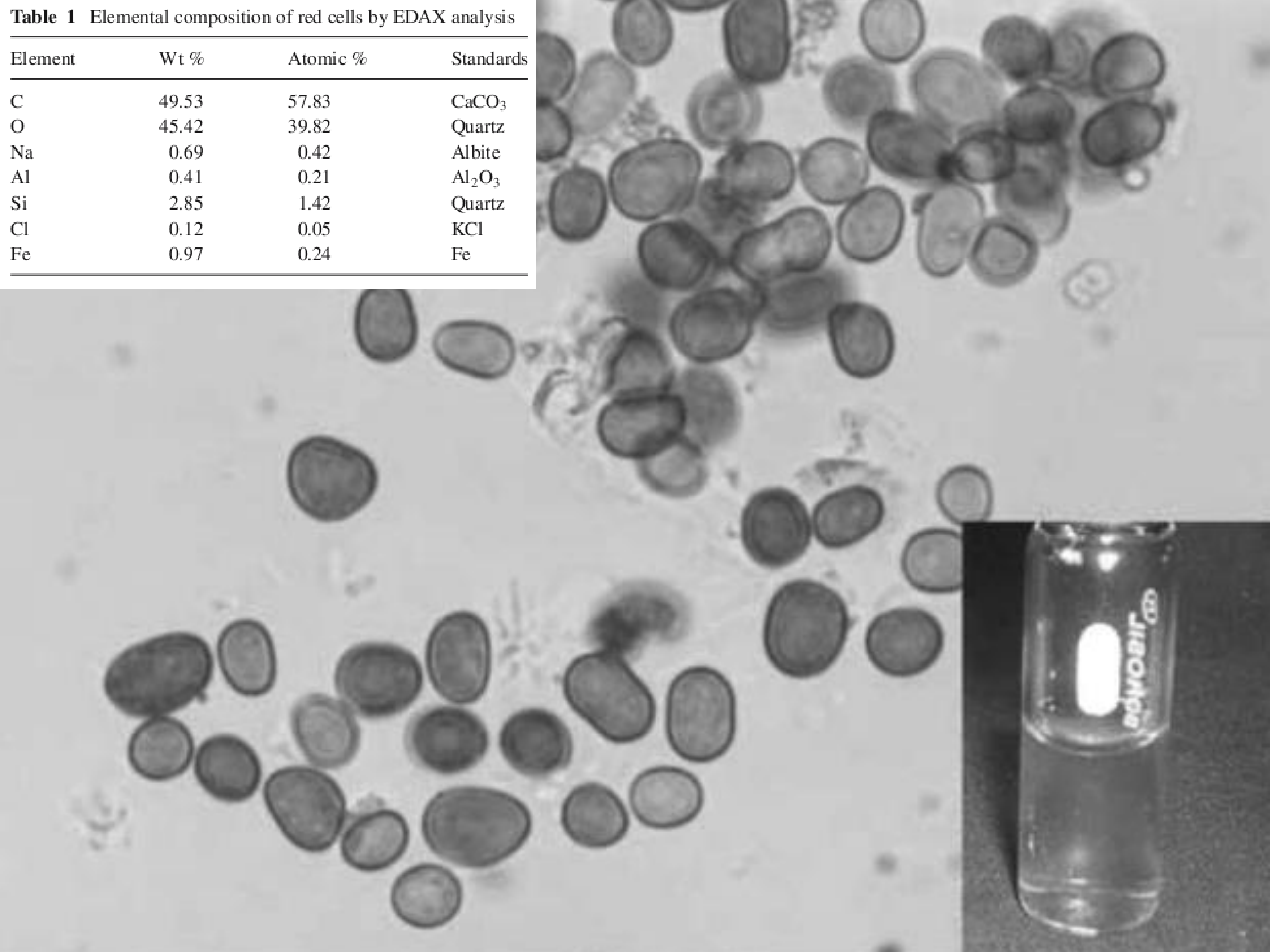
kilometers. Many times it had a sharp boundary, which means while it was raining strongly red at a place a few meters away there were no red rain. The time duration of a typical red rain was not long; usually it lasted for a few minutes to less than about 20 minutes.




kilometers. Many times it had a sharp boundary, which means while it was raining strongly red at a place a few meters away there were no red rain. The time duration of a typical red rain was not long; usually it lasted for a few minutes to less than about 20 minutes.

**Table 1** Elemental composition of red cells by EDAX analysis

| Element | Wt % | Atomic % | Standards |
|---|---|---|---|
| C | 49.53 | 57.83 | $CaCO_3$ |
| O | 45.42 | 39.82 | Quartz |
| Na | 0.69 | 0.42 | Albite |
| Al | 0.41 | 0.21 | $Al_2O_3$ |
| Si | 2.85 | 1.42 | Quartz |
| Cl | 0.12 | 0.05 | KCl |
| Fe | 0.97 | 0.24 | Fe |



# Growth and replication of red rain cells at 121°C and their red fluorescence

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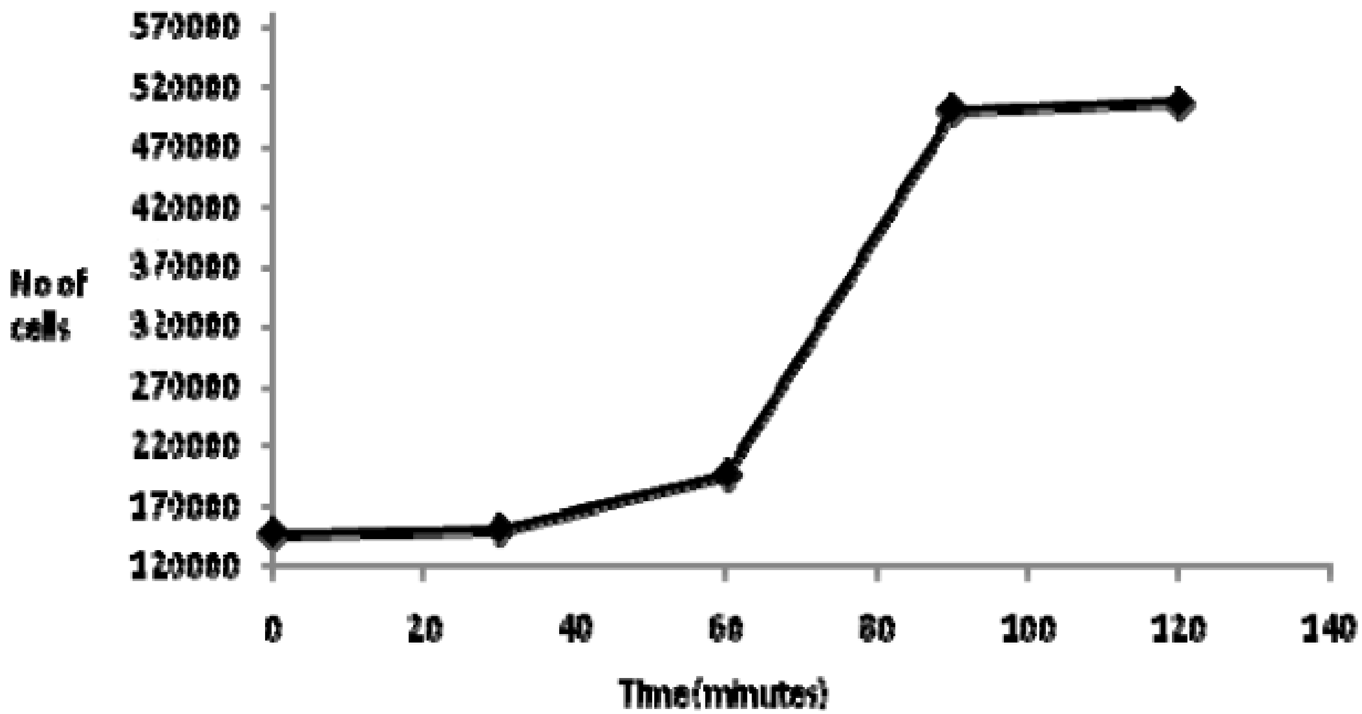
[2]Cardiff Centre for Astrobiology, Cardiff University, Cardiff, CF10 3DY, UK
[3]Department of Molecular Biology and Biotechnology,University of Sheffield. Sheffield, S10 2TN, UK
[4] Astrobiology Division, Department of Physics, Cochin University of Science and Technology, Kochi- 682 022, India

We have shown that the red cells found in the Red Rain (which fell on Kerala, India, in 2001) survive and grow after incubation for periods of up to two hours at 121°C . Under these conditions daughter cells appear within the original mother cells and the number of cells in the samples increases with length of exposure to 121°C. No such increase in cells occurs at room temperature, suggesting that the increase in daughter cells is brought about by exposure of the Red Rain cells to high temperatures. This is an independent confirmation of results reported earlier by two of the present authors, claiming that the cells can replicate under high pressure at temperatures upto 300° C. The flourescence behaviour of the red cells is shown to be in remarkable correspondence with the extended red emission observed in the Red Rectagle planetary nebula and other galactic and extragalactic dust clouds, suggesting, though not proving an extraterrestrial origin.

## 2.1 Cell Culure

Red rain samples (500µl) were inoculated into the 5ml of sterile Luria Bertani (LB) medium (containing, sodium chloride, 10g; peptone,10g; yeast extract, 5g; ditilled water 1liter, pH-7.0). Inoculated samples were separately autocalved for 0.5, 1 hour, 1:30 hour, 2 hours at 121°C. The number of cells present following this treatment was then determined using an heamocytometer (Thomas, Weber, England, depth 0.1mm, 1/400mm$^2$). Cells were counted three times separately and an average of three counts was taken in order to calculate the number of cells in each ml. Uninoculated LB medium(5ml) was included as a control.



# Real cell growth?

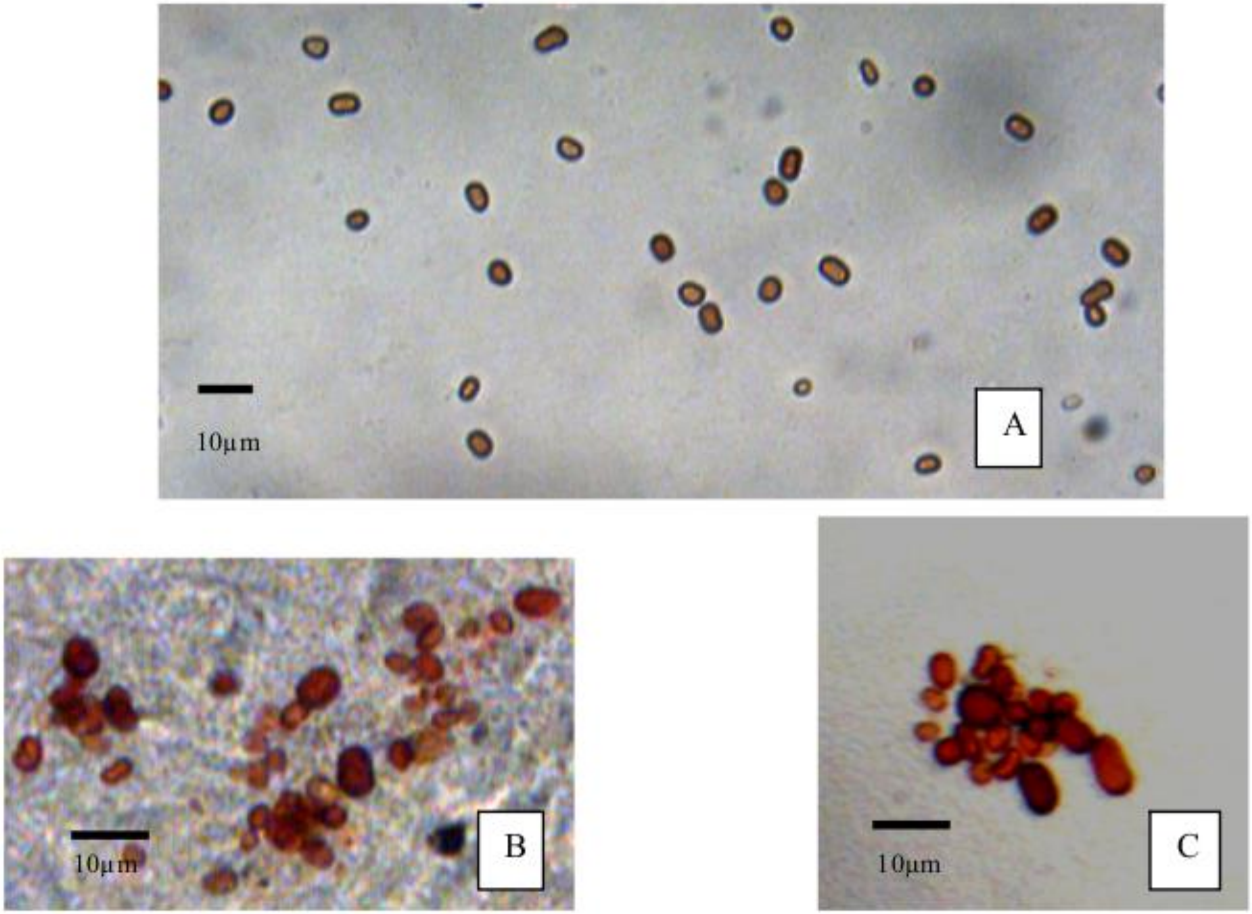



Fig 2. Optical microscope images of red cells: (A) red cells before autoclaving (400x): cells evenly dispersed in the rain water. (B) red cells after 1 hour incubation at 121°C (1000x).(C) after 2 hour incubation at 121°C (1000x).

# But no DNA…

and oxygen. Strangely, a test for DNA using Ethidium Bromide dye fluorescence technique indicates absence of DNA in these cells. In the context of a suspected link between a meteor airburst event and the red rain, the possibility for the extraterrestrial origin of these particles from cometary fragments is discussed.


Need to go there…

# *Types of missions*

- Fly-by
  - Goes past a world just once & continues
- Orbiter
  - Long-term observations, repeated orbits
- Lander or probe
  - Designed to land or probe atmosphere
  - Some landers carry rovers (boat, plane)
- Sample return mission
  - Space craft to return to Earth

# *Fly-bys*

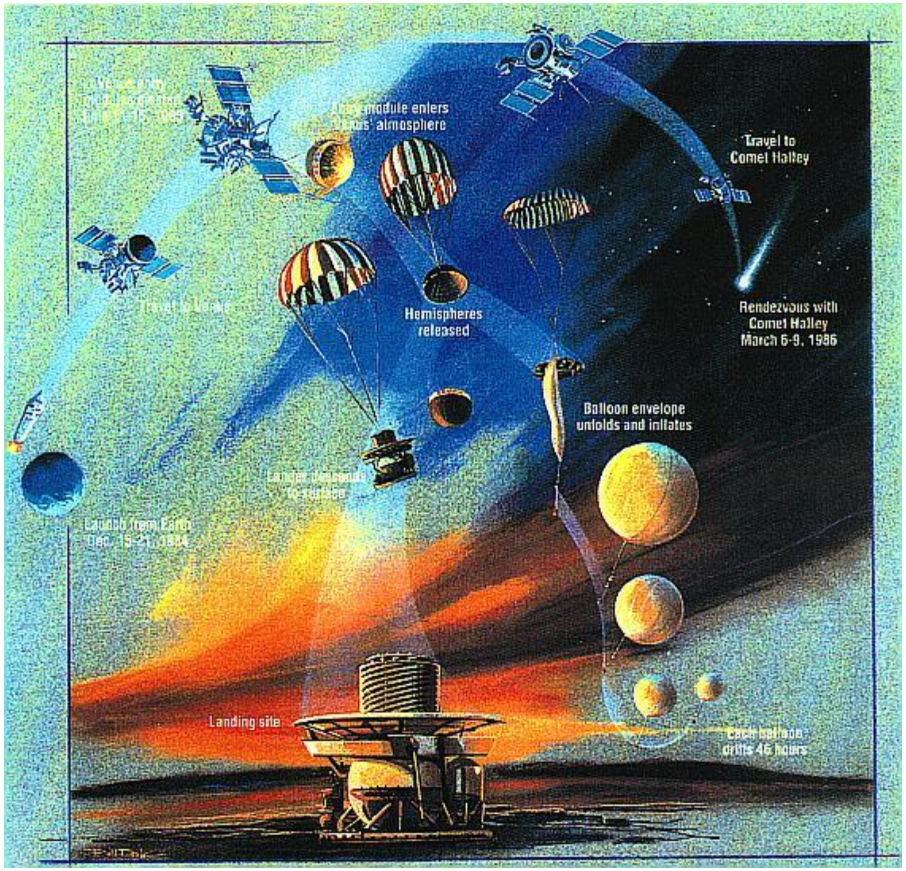
- Much cheaper
  - Fuel needed only for change of trajectory
- Prominent examples:
  - Mariner 4, Voyager 1+2, New Horizons,…
  - Jupiter's rings, magnetic field,
- Additional savings by gravitational assists
  - Stealing a bit of planet's orbital energy
  - For New Horizon: 20% more speed
- Grand constellation of 1980 (BS Fig.7.15)

# *Orbiters*

- Detailed radar mappings
  - Surface altitude, see through clouds,…
- Extra fuel to change orbit
  - Savings for highly elliptic orbits
  - Atmospheric drag: later more circular

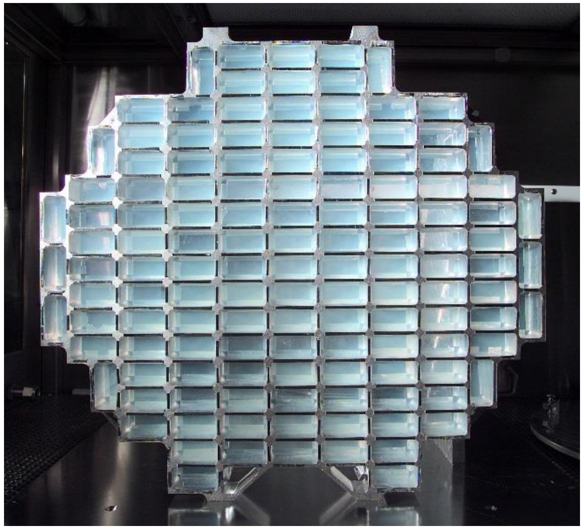
# *Landers & probes*

- Gallileo dropped probe into Jupiter (1995)
- *T*, *P*, composition, radiation, …
- Rovers: Spirit, Opportunity, Curiosity, …
- Planes, balloon, rafts



# Sample returns

- Apollo
- Lunokhod??
- Stardust



# *Names of some comets?*

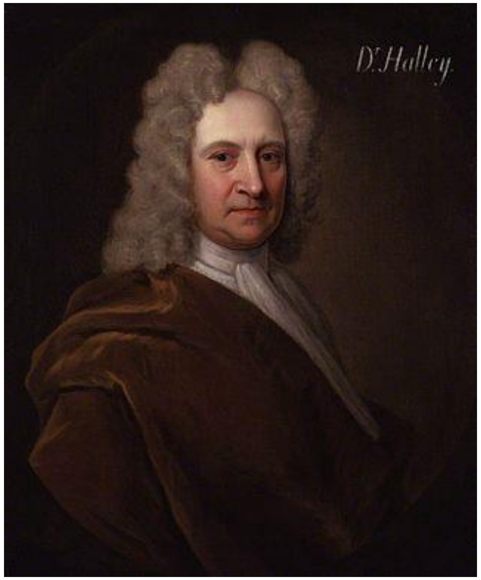
- …
- ……
- ………
- …………

# *Names of some comets?*

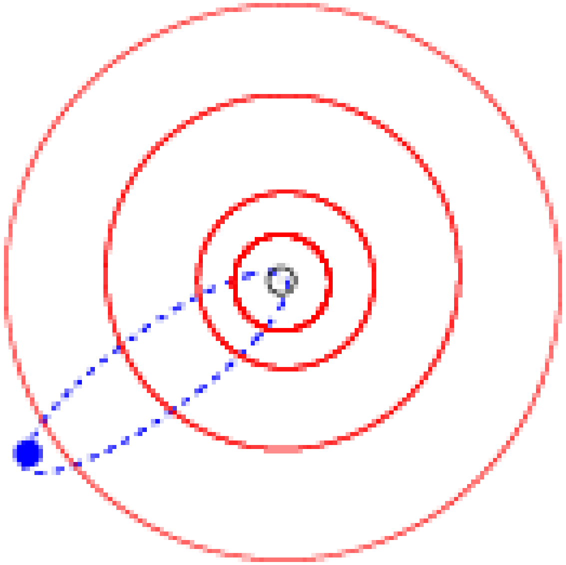
- Halley
- West (1973), Bennett (1970)
- Hale-Bopp (1986), Hyakatake, …
- Kohoutek, …

# *Edmond Halley noticed regularity:*

- 1531
- 1607
- 1682
- 1759
- 1834
- 1910




1656 – 1742

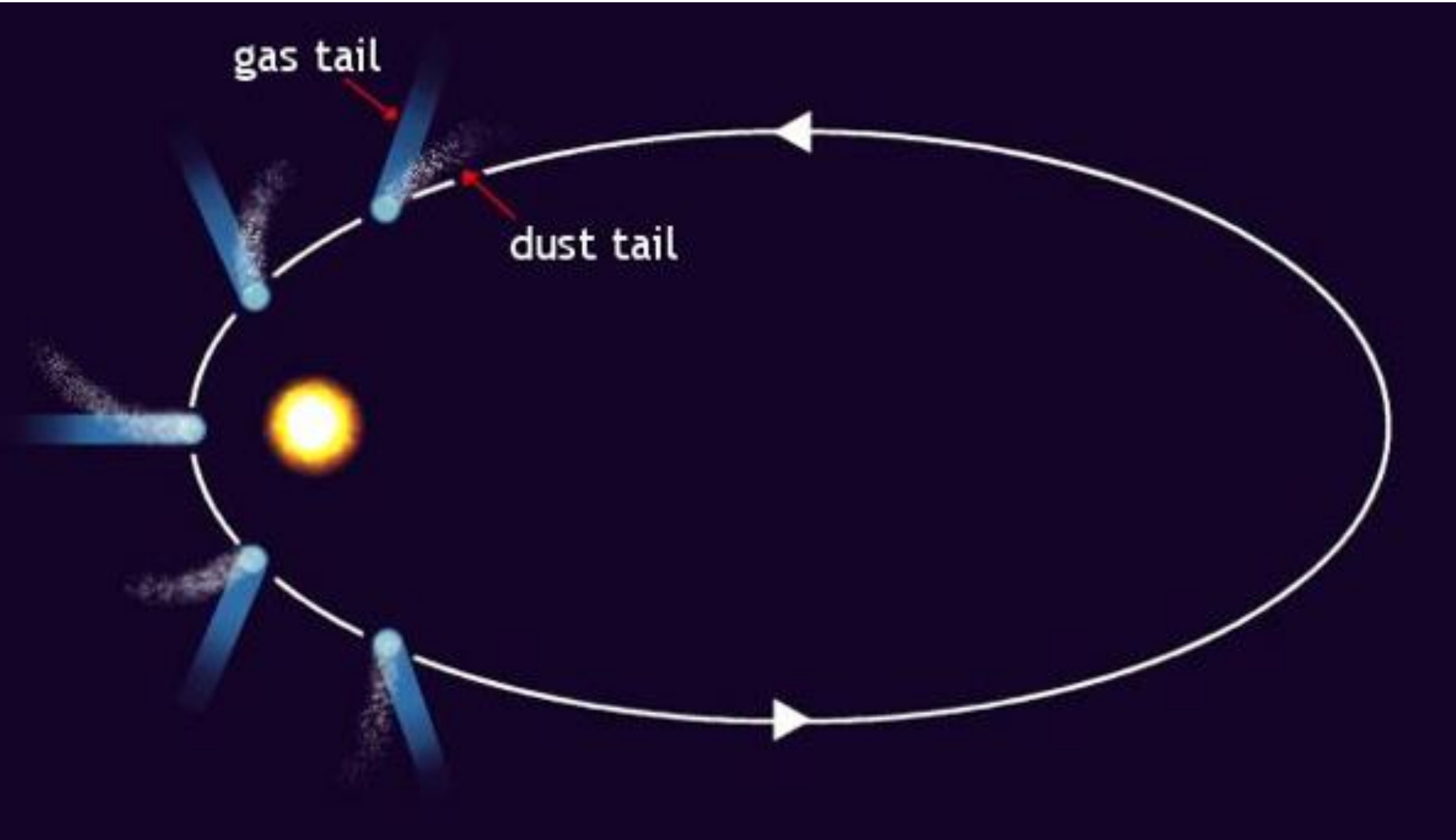


# Halley's comet in 240 BC (+/-?)

七年彗星先出東方見北方五月見西方將軍驁死以攻龍孤慶都還兵攻汲彗星復見西方十六日夏太后死

八年王弟長安君成蟜將軍擊趙反死屯留軍吏皆斬死遷其民於臨洮將軍壁死卒屯留蒲鶮反戮其屍河魚大上輕車重馬東就食嫪毐封為長信侯予之山陽地令毐居之宮室車馬衣服苑囿馳獵恣毐事無小大皆決於毐又以河西

# The 2 tails of comets

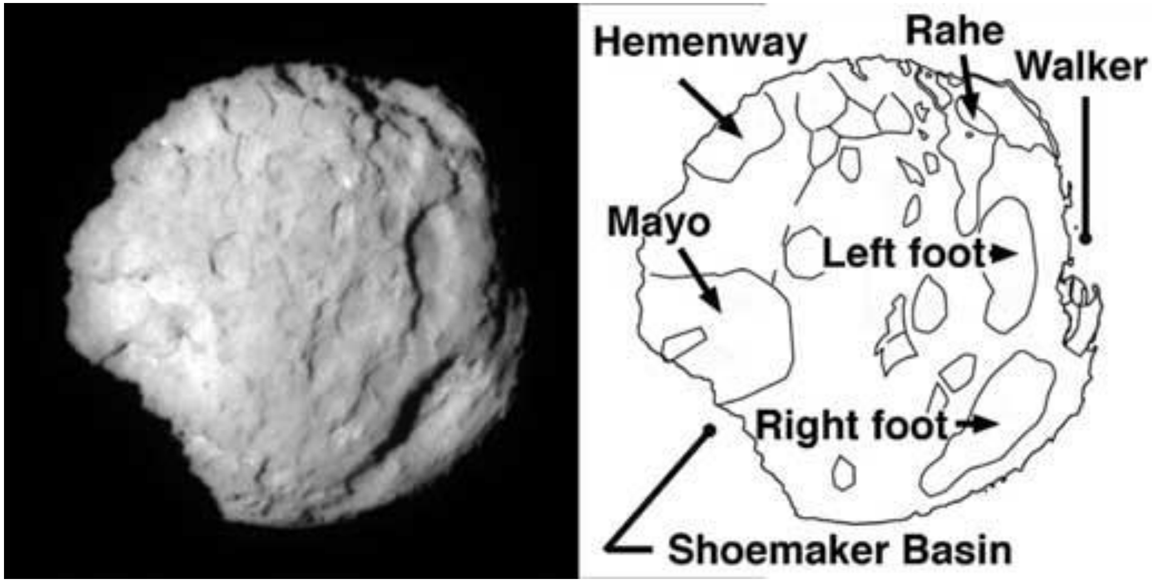


# Comet missions since 1978

| Spacecraft | Launch Date[1] | Operator | Comet | Mission | Outcome | Remarks | Carrier rocket[2] |
|---|---|---|---|---|---|---|---|
| ICE (ISEE-3) | 12 August 1978 | NASA United States / ESA | 21P/Giacobini–Zinner | Flyby | Successful | Extended mission; Closest approach of 7,862 kilometres (4,885 mi) at 11:02 UTC on 11 September 1985. Also made distant observations of 1P/Halley in May 1986.[3] | Delta 2914 |
| Vega 1 (5VK No.901) | 15 December 1984 | Soviet Union | 1P/Halley | Flyby | Successful | Flew past Halley after visiting Venus; closest approach 8,889 kilometres (5,523 mi) at 07:20:06 UTC on 6 March 1986.[4] | Proton-K/D-1 |
| Vega 2 (5VK No.902) | 21 December 1984 | Soviet Union | 1P/Halley | Flyby | Successful | Flew past Halley after visiting Venus; closest approach at 07:20 UTC on 9 March 1986.[5] | Proton-K/D-1 |
| Sakigake (MS-T5) | 7 January 1985 | ISAS Japan | 1P/Halley | Flyby | Successful | Closest approach of 6.99 million kilometres (4.34 million miles) at 04:18 UTC on 11 March 1986.[6] | Mu-3S-II |
| Giotto | 2 July 1985 | ESA | 1P/Halley | Flyby | Successful | Closest approach of 605 kilometres (376 mi) at 00:03:02 UTC on 14 March 1986.[7] | Ariane 1 |
| Giotto | 2 July 1985 | ESA | 26P/Grigg–Skjellerup | Flyby | Successful | Extended mission. Closest approach of 200 kilometres (120 mi) at 15:30 UTC on 10 July 1992.[7] | Ariane 1 |
| Suisei (PLANET-A) | 19 August 1985 | ISAS Japan | 1P/Halley | Flyby | Successful | Closest approach of 152,400 kilometres (94,700 mi) at 13:06 UTC on 8 March 1986[8] | Mu-3S-II |
| Suisei (PLANET-A) | 19 August 1985 | ISAS Japan | 21P/Giacobini–Zinner | Flyby | Spacecraft failure (Extended mission) | Extended mission, spacecraft ran out of fuel en route; flyby had been scheduled for 24 November 1998[8] | Mu-3S-II |
| Deep Space 1 | 24 October 1998 | NASA United States | 107P/Wilson–Harrington[9] | Flyby | Spacecraft failure | Spacecraft was unable to reach Wilson–Harrington due to ion engine operation being suspended while a problem with the probe's star tracker was investigated.[10] | Delta II 7326 |
| Deep Space 1 | 24 October 1998 | NASA United States | 19P/Borrelly | Flyby | Successful | Extended mission | Delta II 7326 |
| Stardust (Discovery 4) | 7 February 1999 | NASA United States | 81P/Wild | Flyby Sample return | Successful | | Delta II 7426 |
| Stardust (Discovery 4) | 7 February 1999 | NASA United States | 9P/Tempel | Flyby | Successful | Extended mission, Stardust-NExT, to survey crater caused by Deep Impact | Delta II 7426 |
| CONTOUR (Discovery 6) | 3 July 2002 | NASA United States | 2P/Encke | Flyby | Spacecraft failure | | Delta II 7425 |
| CONTOUR (Discovery 6) | 3 July 2002 | NASA United States | 73P/Schwassmann–Wachmann | Flyby | Spacecraft failure | | Delta II 7425 |
| CONTOUR (Discovery 6) | 3 July 2002 | NASA United States | 6P/d'Arrest | Flyby | Spacecraft failure | Flyby provisionally scheduled at time of spacecraft's failure | Delta II 7425 |
| Rosetta | 2 March 2004 | ESA | 67P/Churyumov–Gerasimenko | Orbiter | Operational | Entered orbit around 67P at 09:06 UTC on 6 August 2014. | Ariane 5G+ |
| Philae | 2 March 2004 | ESA / DLR Germany | 67P/Churyumov–Gerasimenko | Lander | Mostly successful | Carried by Rosetta. Came to rest on the surface of 67P at 17:32 UTC on 12 November 2014. Communications ceased with the loss of battery power at 00:36 UTC on 15 November 2014 and the lander began hibernating. Reactivated on solar power and briefly established contact with ground control again at 20:28 UTC on 13 June 2015, and sporadically until 9 July 2015 when the last communication was received.[11][12] | Ariane 5G+ |
| Deep Impact (Discovery 7) | 12 January 2005 | NASA United States | 103P/Hartley | Flyby | Successful | Extended mission (EPOXI) | Delta II 7925 |
| Deep Impact (Discovery 7) | 12 January 2005 | NASA United States | 9P/Tempel | Flyby/Impactor | Successful | Impact occurred at 05:52 UTC on 4 July 2005. | Delta II 7925 |

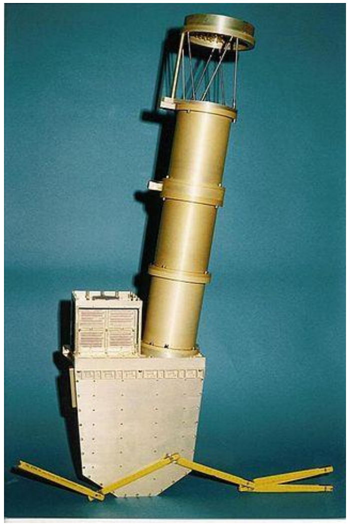
# *Stardust → Wild 2 (2004)*

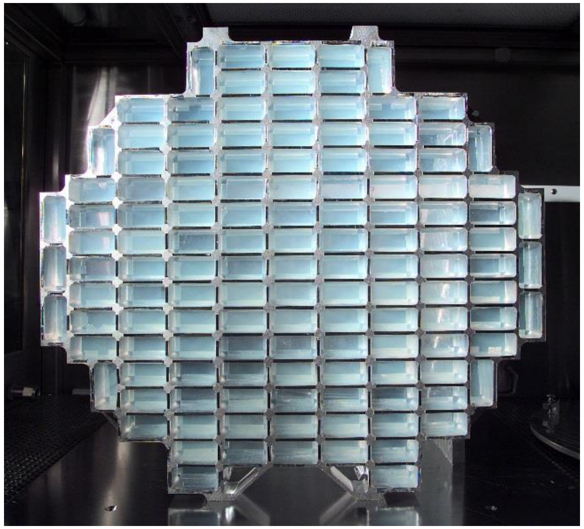
- Returned, landed in Utah 2006
- Pure carbon, olivine $(MgFe)_2SiO_4$
- Many organic compounds




# *Dust collector*

- Cometary & Interstellar Dust Analyser (CIDA)
- Stardust Sample Collector (SSC)
- Aerogel (low density, inert, …)



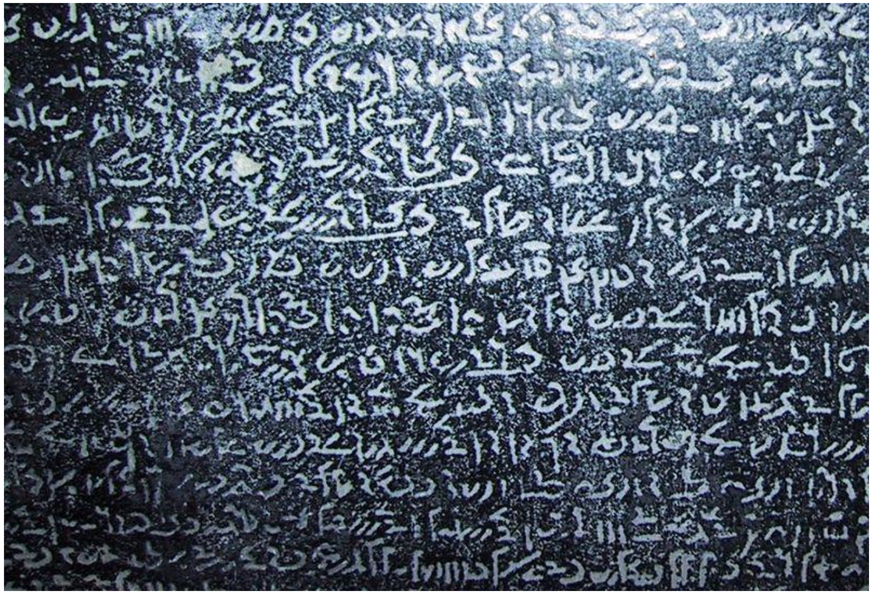


# *Dirty snowballs?*

- Composition of 67P: 80% $H_2O$, 10% $CO$, 4.5% $CH_4$+$NH_3$

# *Rosetta & Philae*

- Rosetta: 3 languages
  - Hieroglyphs+Greek+Demotic
- Philae obelisk: 2 lang.



# *Rosetta mission*

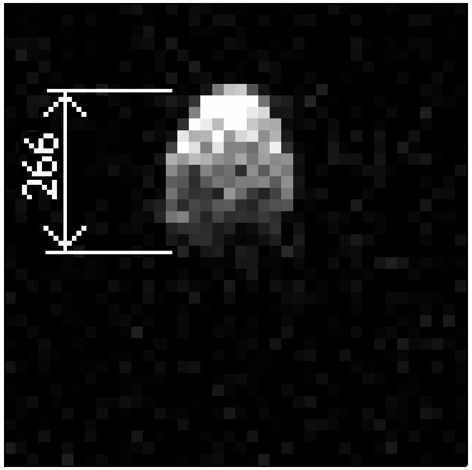
- ESA, launch March 2004
- Lander: Philae
- Comet 67P/Churyumov-Gerasimenko
  - P for periodic
- Size 30x10 km

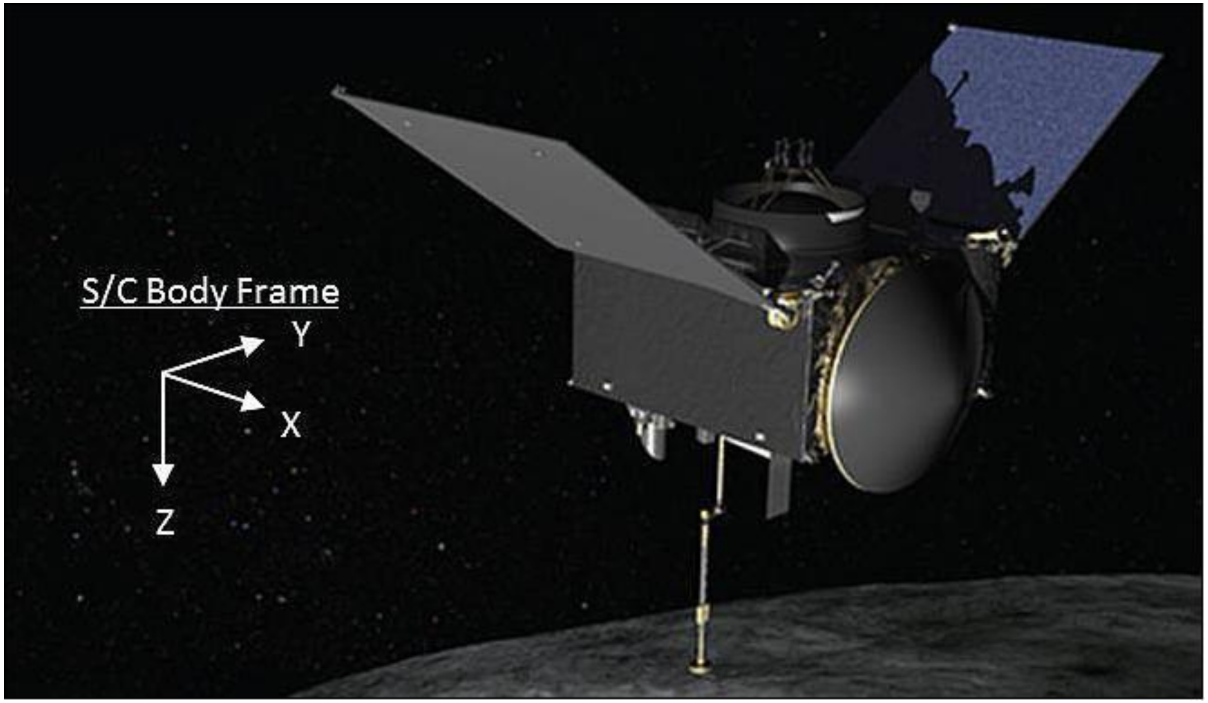
# *Rosetta mission*

- Reached it on Aug 14, 2014 + orbit
- Power restored June/July 2015
- High D/H=$5.3x10^{-4}$ (low for JFC)
- Glycine (the only amino acid?)
- Oxygen gas around it

# *OSIRIS-REx*

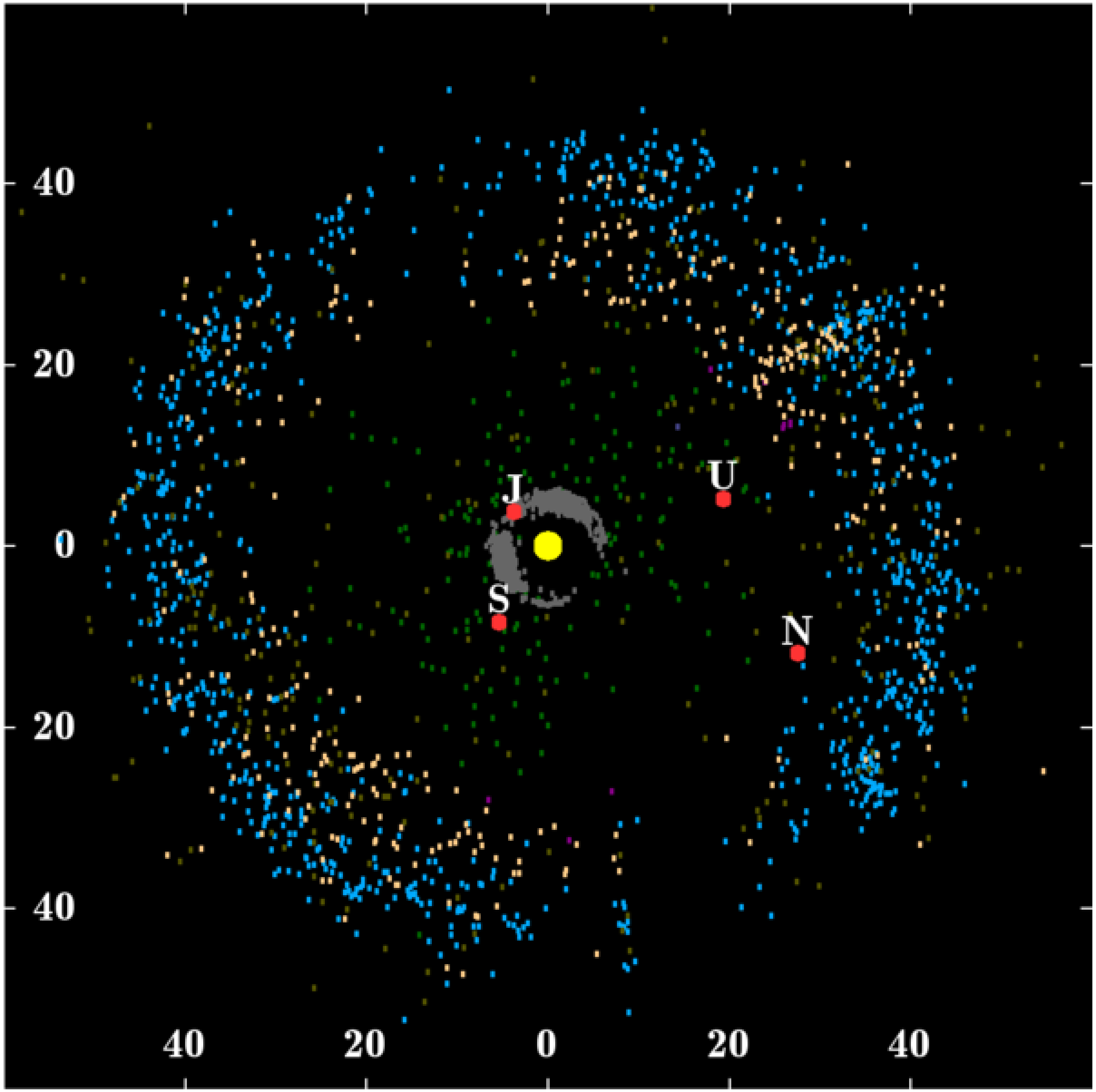
- Sept 2016 launch
- On route to 101955 Bennu
- Carbonaceous asteroid



# Kuiper Belt Objects

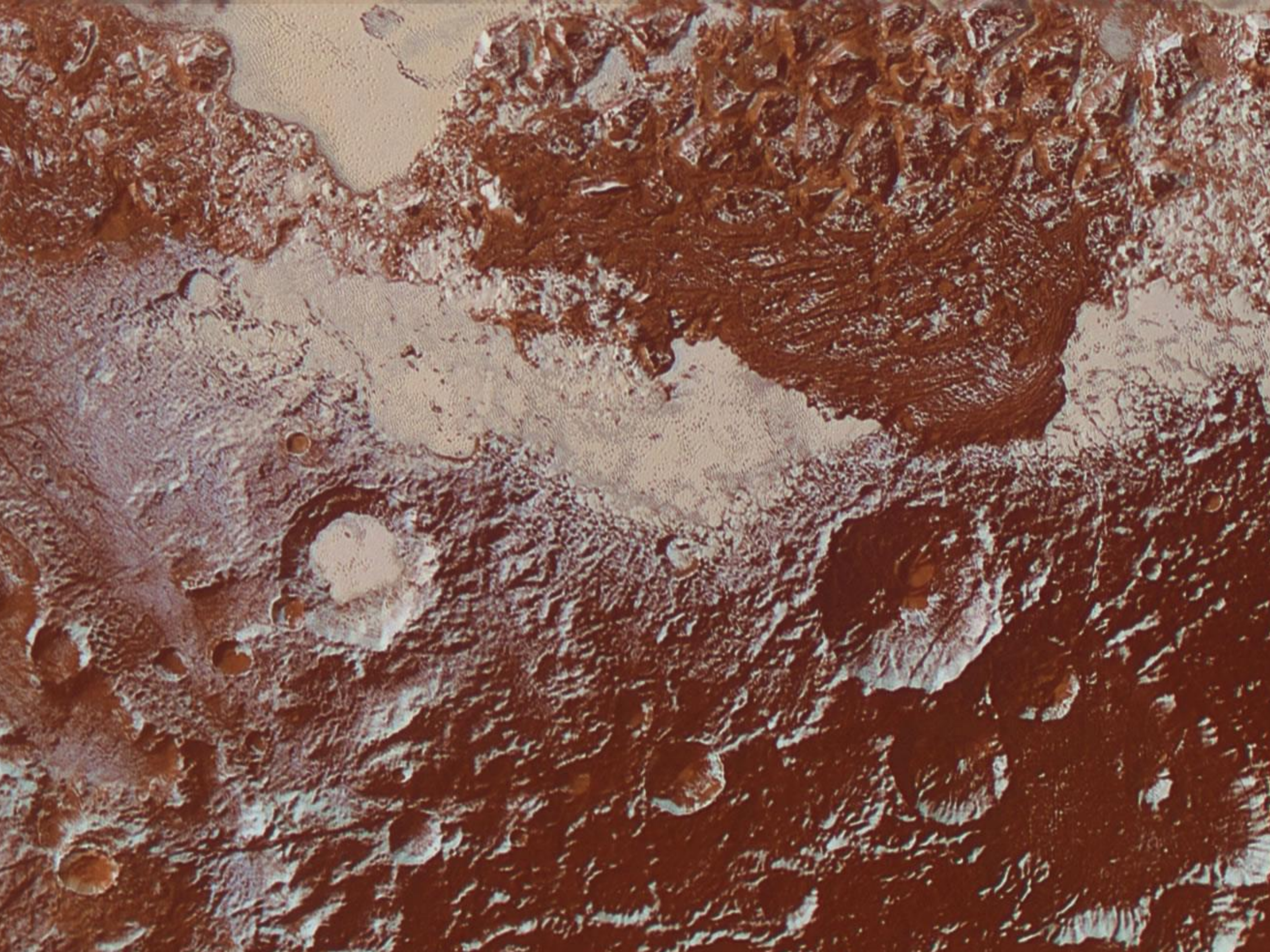
- Similar to asteroid belt
- Now thousands since 1992
- Frozen volatiles (methane, ammonia, water)
- Pluto is one of them!



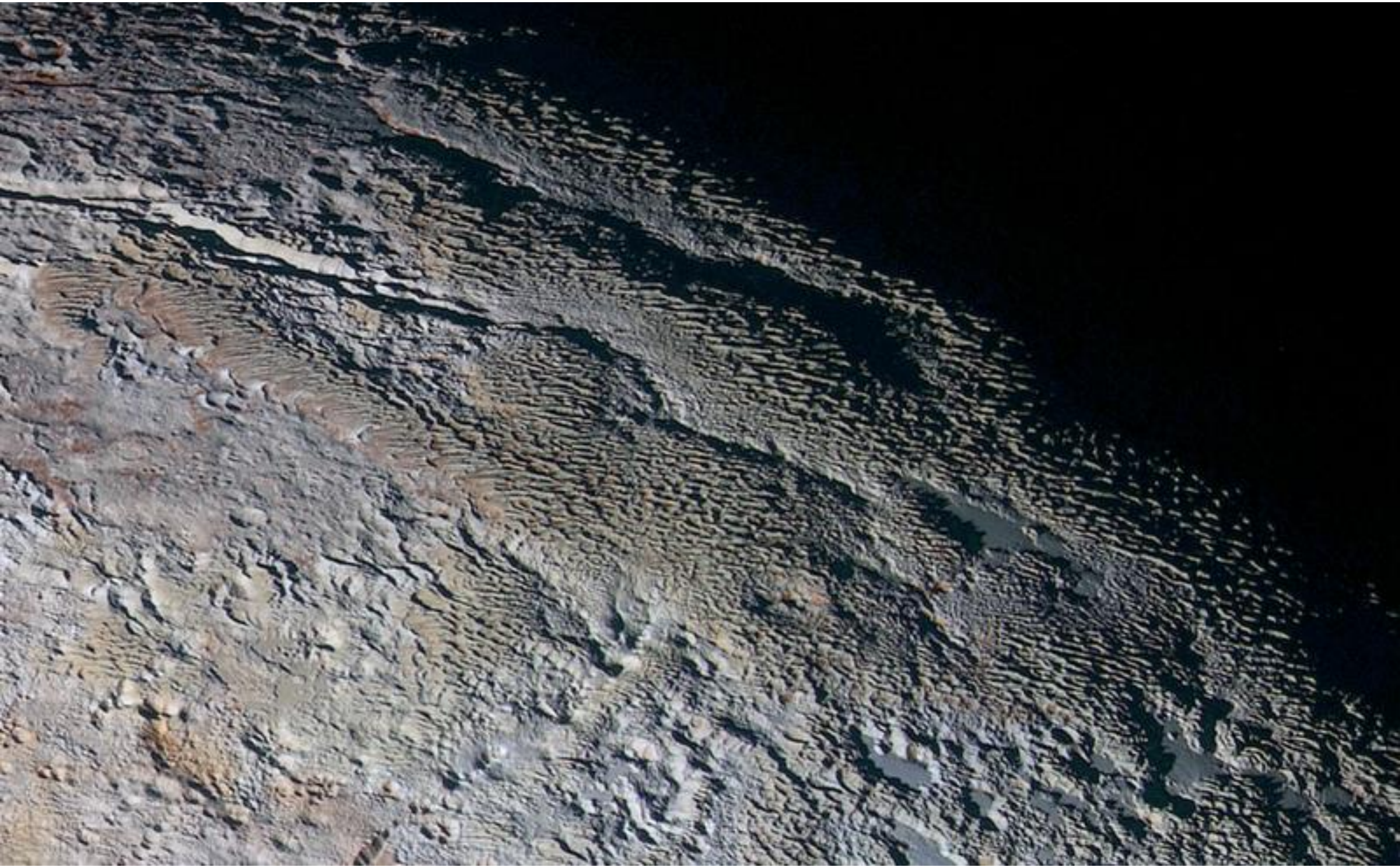
# *Why Pluto is not a planet*

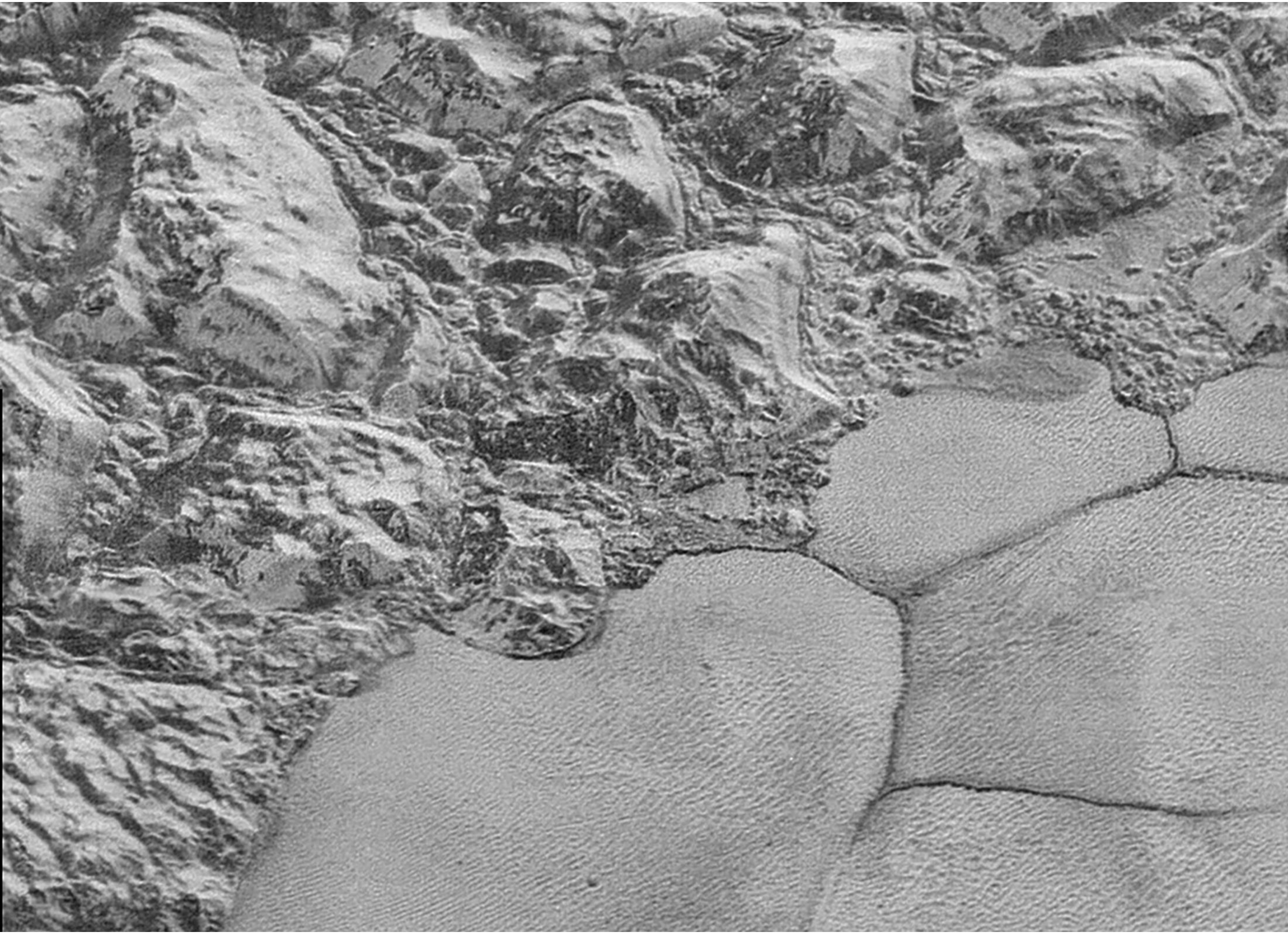
- Pluto is no longer a planet. But why is that?
- Clyde Tombaugh discovered Pluto in 1930
- From 1930 until 2006, beyond Neptune as the ninth planet in our solar system
- In 2006, however, the definition of a planet was changed!
- new rules adopted by the International Astronomical Union, to qualify as a planet:
- A planet must be round.
- A planet must orbit the sun.
- A planet must have “cleared the neighborhood" of its orbit.

- This means that as a planet travels, its gravity sweeps and clears the space around it of other objects. Some of the objects may crash into the planet, others may become moons.
- Pluto follows the first two rules: It does not, however, follow the third rule.
- It has not yet cleared the neighborhood of its orbit in space.

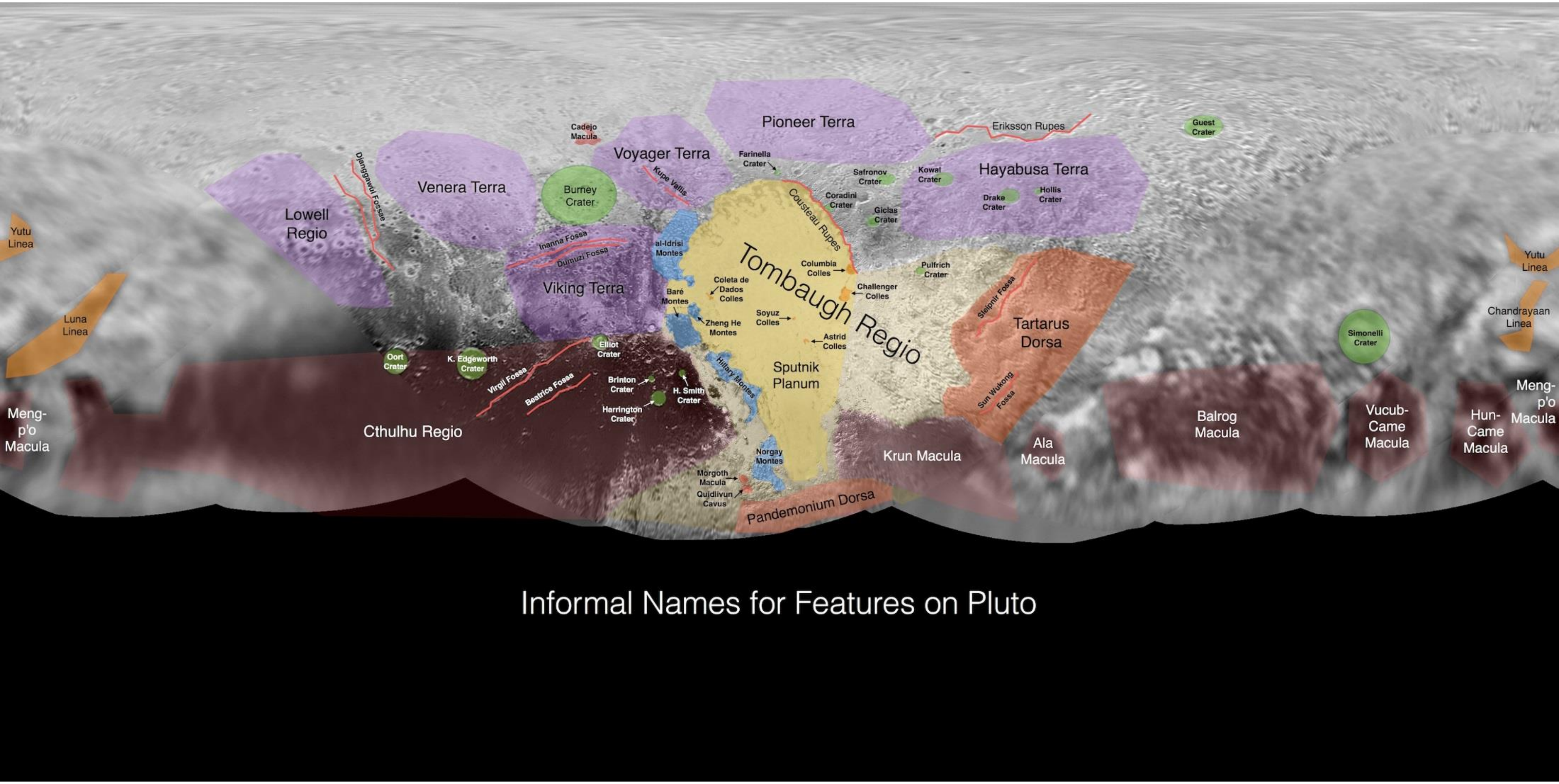


# Strange surface patters





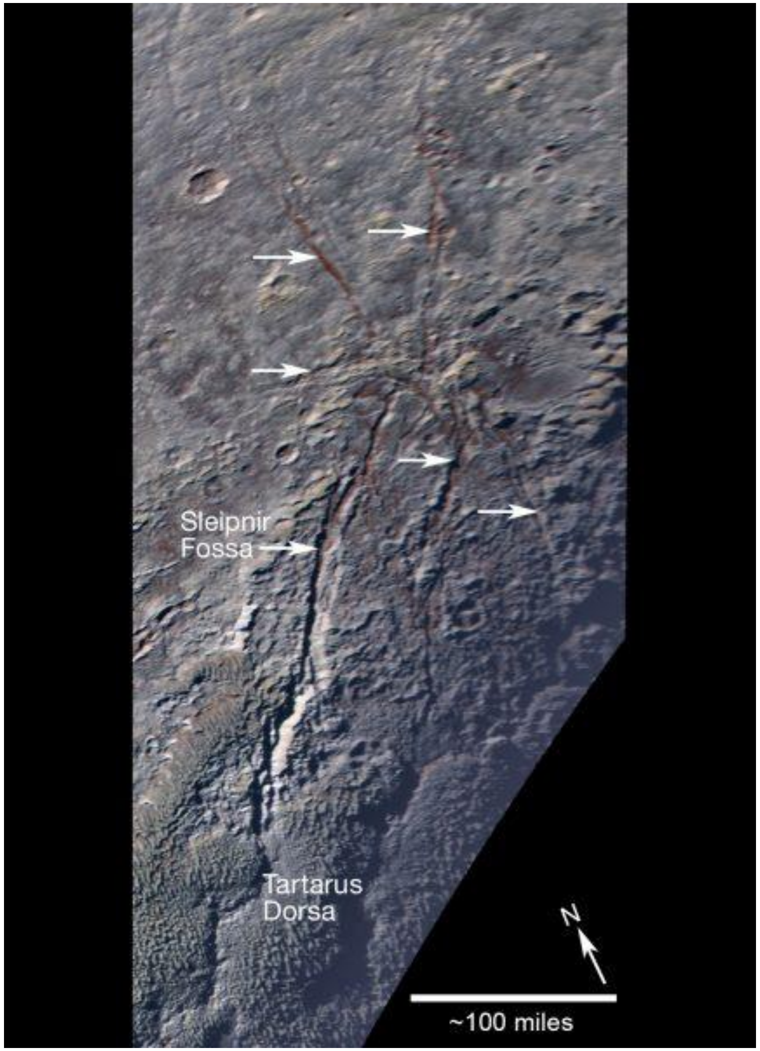
# *Names on Pluto's surface*




Convection 10 cm/yr, faster than continental drift

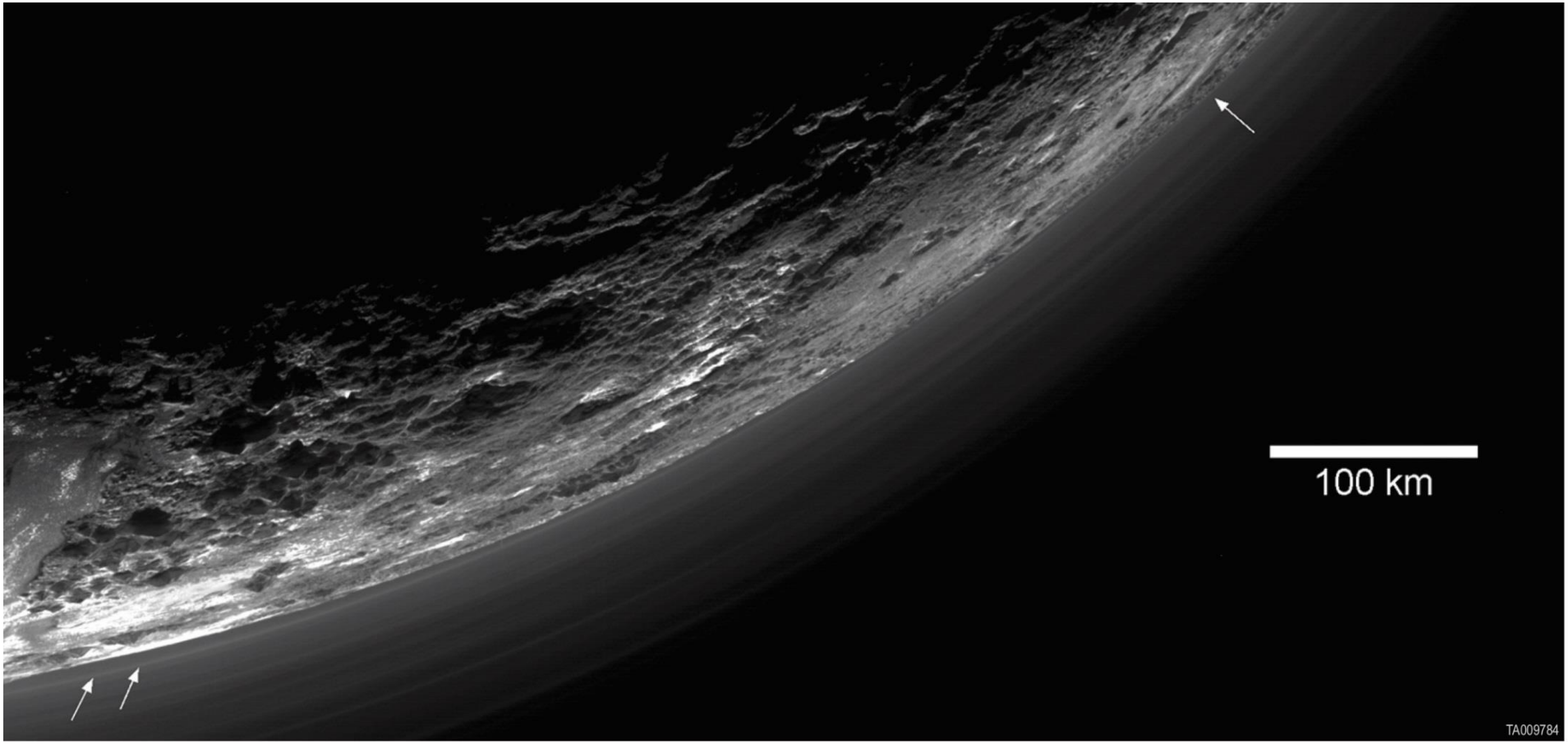
# Motions on Pluto

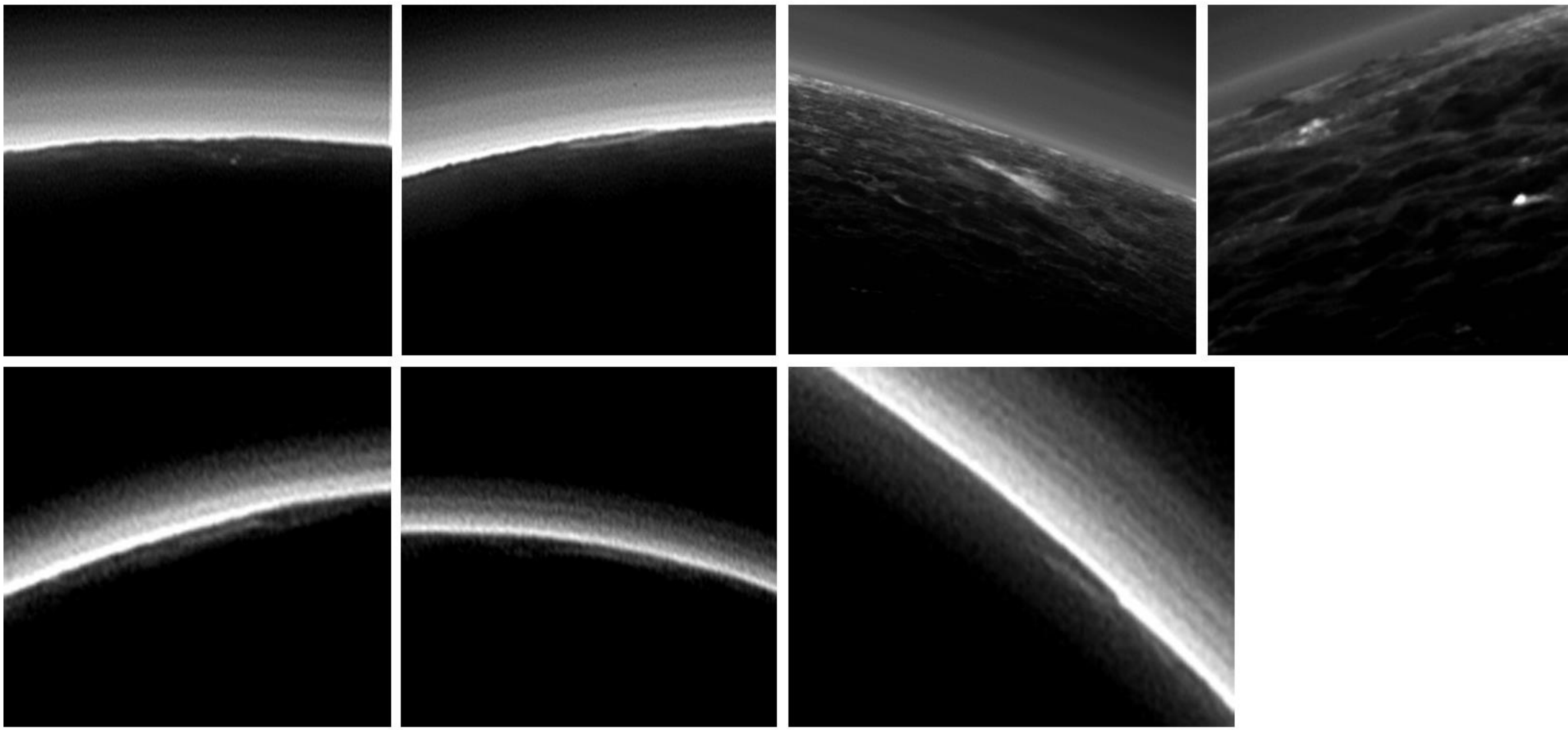
- Also has liquid ocean
- Subsurface habitat?
- Time scales ~1Myr

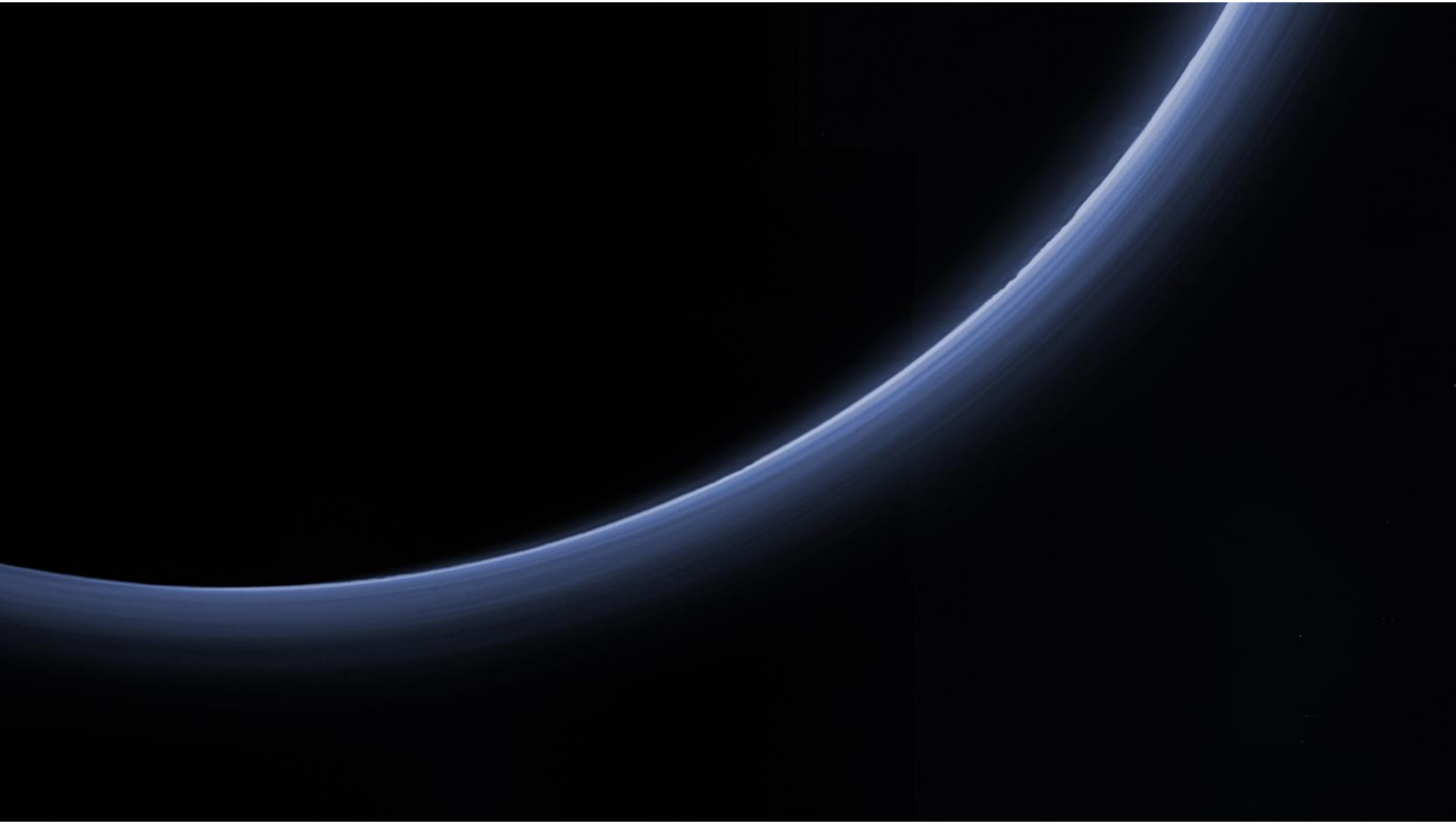


# *Pluto Clouds?*

- Pluto's hazy atmosphere is almost entirely free of clouds
- some cloud candidates after examining images taken by the New Horizons Long Range Reconnaissance Imager and Multispectral Visible Imaging Camera
- All are low-lying, isolated small featuresless cloud decks
- suggestive of possible, rare condensation clouds.


100 km
TA009784





# *So why $N_2$ in Titan?*

A. Is more massive
B. From subsurface ocean
C. From $NH_3$
D. From lightning

# *So why $N_2$ in Titan?*

A. Is more massive
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# *Next time*

- Exoplanets
- Their first discoveries

- Rothery et al. 233 – 252
- Longstaff: pp 321 – 342
- BS: 336 – 339, 370 – 395