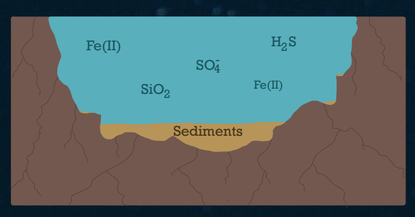
Delivering prebiotic feedstocks with cometary impacts

Catriona H. McDonald[1], Amy Bonsor[1], Paul Rimmer[2], Auriol Rae[3], Richard Anslow[1]

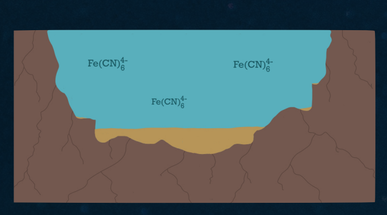
[1]Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge, CB3 0HA, UK
[2]Astrophysics Group, Cavendish Laboratory, University of Cambridge, JJ Thomson Ave, Cambridge, CB3 0HE, UK
[3]Department of Earth Sciences, University of Cambridge, Cambridge, CB2 3EQ, UK

Delivery scenario

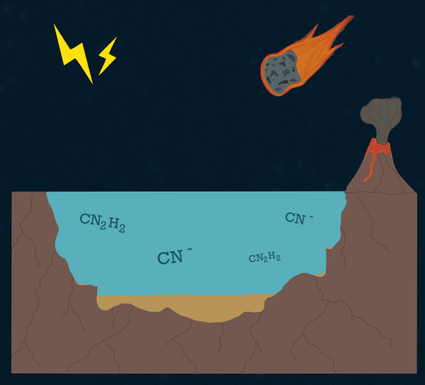
One particular scenario for the origins of life on the early Earth invokes cometary delivery in the following way[2]…



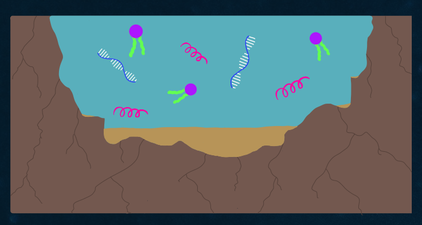
An isolated body of water with important molecules…



…is impacted by a comet which delivers hydrogen cyanide (HCN).



Additional energy activates the cyanosulfidic pathway to life…



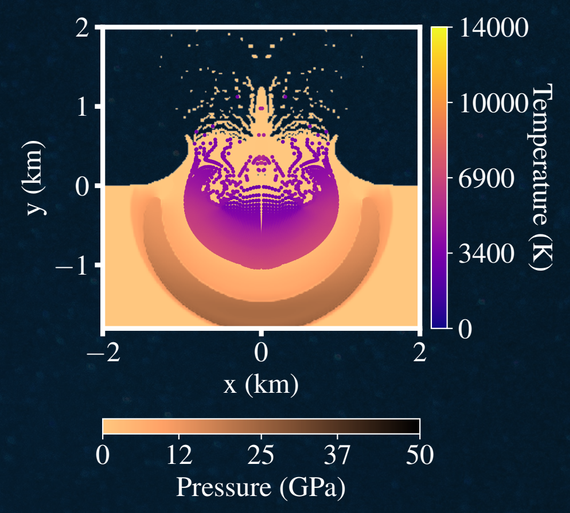
…which leads to the formation of RNA, lipid and protein precursors[1].

This work aims to determine how effective cometary impacts are at delivering HCN.

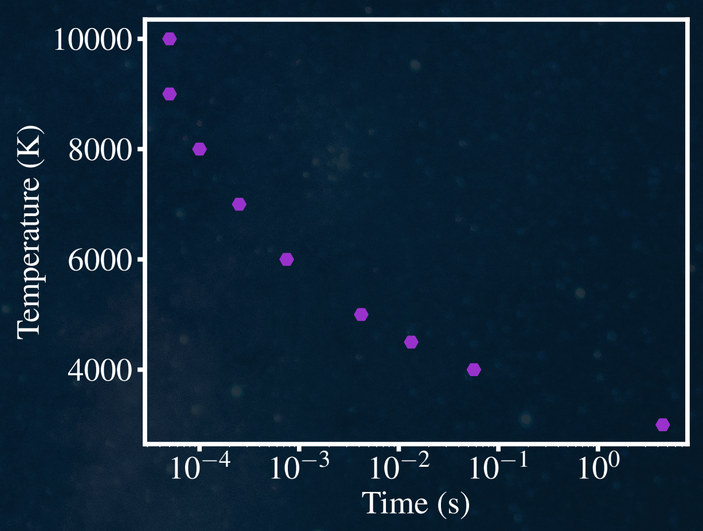
Methods

Impact simulations

- iSALE grid-based hydrocode
- Spherical comet made of pure water ice with a homogeneous HCN distribution
- Solid basalt impact site to simulate surface of early Earth



A simulated impact of a 1km comet hitting the surface of the early Earth with v_{imp} = 20 kms^{-1}. The temperature data traces the material of the comet.



The time taken for 99% of HCN to degrade at different temperatures with our simple chemical model.

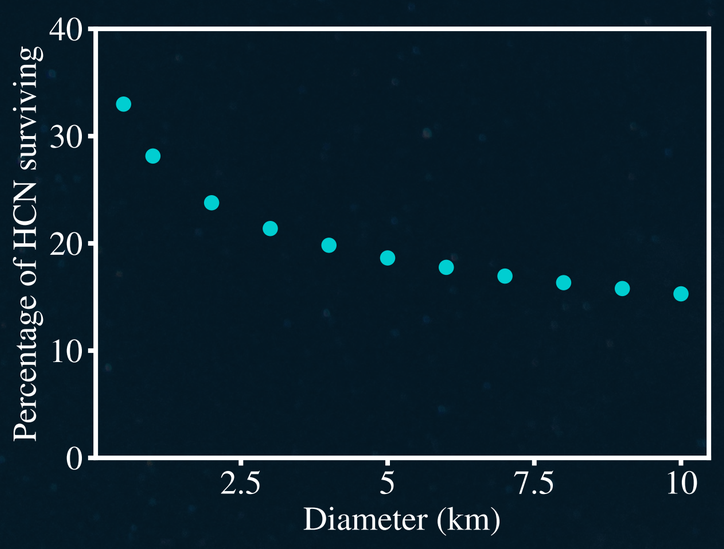
Chemical Modelling

- Simple model:
  - Thermal decomposition of H_2O
  - Radical driven destruction of HCN

Which cometary impacts are most efficient at delivery?[3,4]

Small…

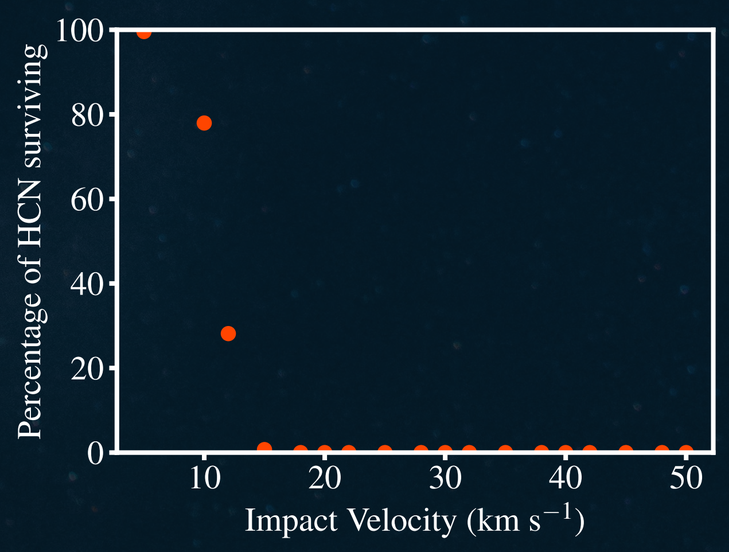
The impact shockwave passes through smaller bodies quicker, reducing the time the material stays at high temperatures, boosting HCN survival.



The percentage of HCN which survives an impact at v_{imp} =12 km s^{-1} for a range of impactor diameters.

…slow…

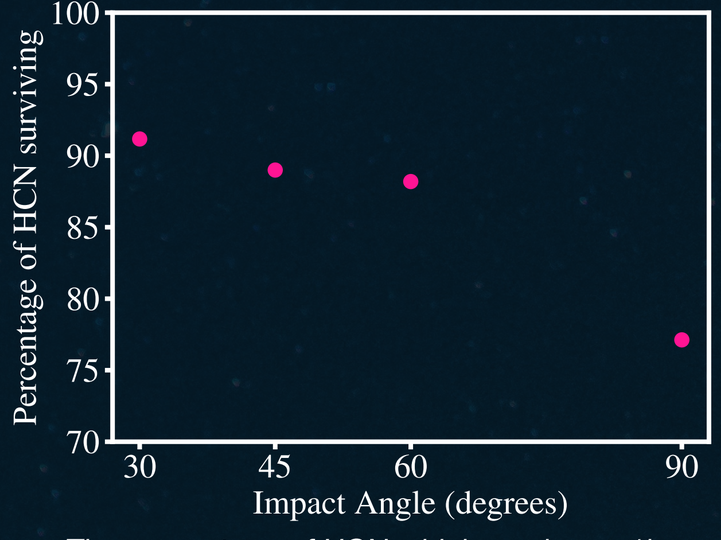
Higher impact velocities increase the temperatures experienced by the cometary material, efficiently destroying HCN.



The percentage of HCN which survives a 1km diameter comet impacting at a range of impact velocities.

& oblique.

Oblique impacts reduce the temperature experienced by the cometary material increasing HCN survival.



The percentage of HCN which survives a 1km diameter comet impacting at 10 km s^{-1} for a range of impact angles.

References

[1] Patel et al., 2015. Nature Chemistry 7, 301–307. doi: 10.1038/nchem.2202
[2] Sasselov, Grotzinger, & Sutherland, 2020. Science Advances 6, eaax3419. doi: 10.1126/sciadv.aax3419
[3] Pierazzo & Chyba, 1999. Meteoritics & Planetary Science 34, 909–918. doi:10.1111/.1945-5100.1999.tb01409.x
[4] Todd & Öberg, 2020. Astrobiology 20, 1109–1120. doi: 10.1089/ast.2019.2187

Scan here to see successful and unsuccessful impacts!

Background image: Nicole Avagliano