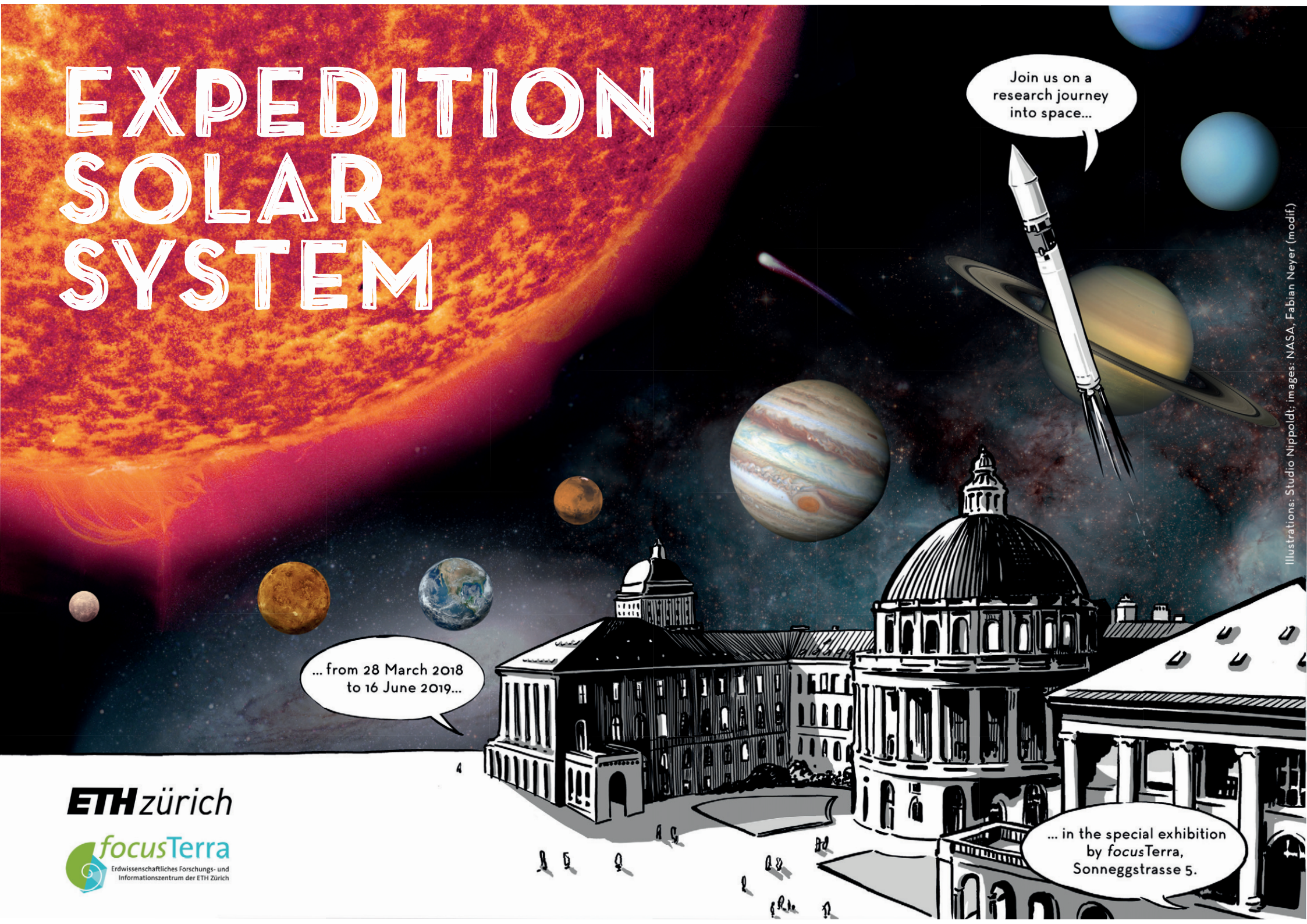

EXPEDITION SOLAR SYSTEM
Join us on a research journey into space...
... from 28 March 2018 to 16 June 2019...
... in the special exhibition by focusTerra, Sonneggstrasse 5.
ETH zürich
focusTerra
Erdwissenschaftliches Forschungs- und Informationszentrum der ETH Zürich
Illustrations: Studio Nippoldt; images: NASA, Fabian Neyer (modif.)

OUR SOLAR SYSTEM

Stars like our **Sun** consist of a mixture of gases and are so hot that nuclear fusion occurs inside them. The energy this releases is what makes stars shine, and depending on their temperature, they may be blue, yellow, orange or red.

OUR STAR

- ca 1.4 million km (110 x Earth)
- 5,500 °C (15 million °C in the core)
- 100 kg = 2,800 kg
- no orbit
- 1 solar day = 25 Earth days
- no moons

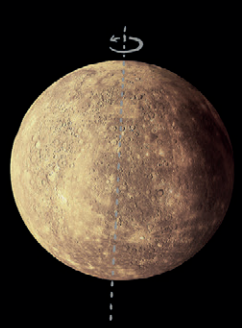
THE HOTTEST ONE

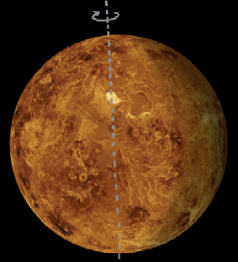
- ca 12,000 km (almost like Earth)
- up to 470 °C
- 100 kg = 91 kg
- 1 year on Venus = 225 Earth days
- 1 day on Venus = 117 Earth days
- no moons

THE RED ONE

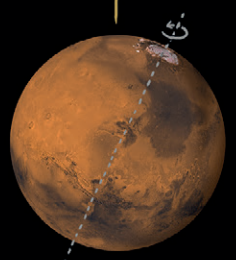
- ca 6,800 km (1/2 Earth)
- -153 °C to 20 °C
- 100 kg = 38 kg (like on Mercury)
- 1 year on Mars = 687 Earth days
- 1 day on Mars = ca 1 Earth day
- 2 moons: **Phobos, Deimos**

Terrestrial planets





MOON



SUN
Distance from the Sun
AU = astronomical unit (Earth = 1 AU)

MERCURY
58 million km
= 0.4 AU

VENUS
108 million km
= 0.7 AU

EARTH
150 million km
= 1 AU

MARS
228 million km
= 1.5 AU

THE FASTEST ONE

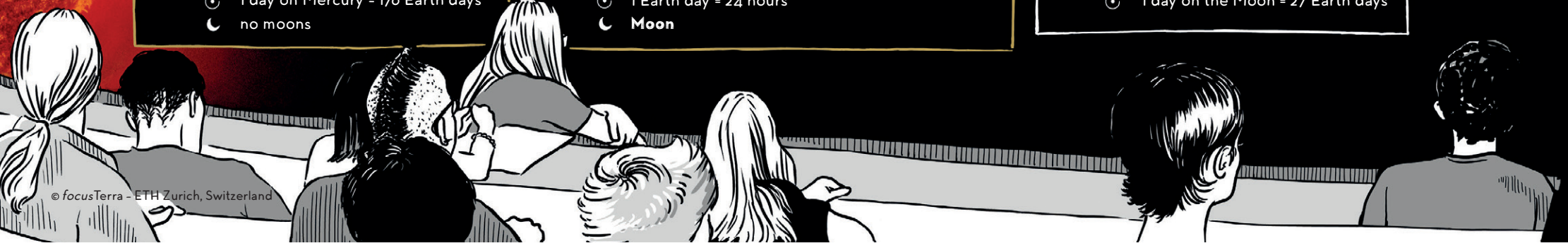
- ca 5,000 km (1/3 Earth)
- -173 °C to 427 °C
- 100 kg = 38 kg
- 1 year on Mercury = 88 Earth days
- 1 day on Mercury = 176 Earth days
- no moons

OUR HOME

- 12,742 km
- -88 °C to 58 °C (average: 15 °C)
- 100 kg = 100 kg
- 1 Earth year = 365 days and 6 hours
- 1 Earth day = 24 hours
- **Moon**

MOON

- ca 3,400 km (1/4 Earth)
- -233 °C to 123 °C
- 100 kg = 16 kg
- takes 27 days to orbit Earth
- 1 day on the Moon = 27 Earth days



Terrestrial (Earth-like) **planets** are mainly made of rock. They have a solid surface and possibly a metallic core.

Gas giants consist mainly of light elements, such as hydrogen (H) and helium (He), which may be liquid or solid in the interior due to high pressure and low temperatures.

Planets whose gases are mainly solid (e.g. in the form of ice) are referred to as **ice giants**.

COMETS

DWARF PLANET IN THE ASTEROID BELT

- ca 950 km
- -140 °C to -70 °C
- 100 kg < 3 kg
- 1 year on Ceres = 4.6 Earth years
- 1 day on Ceres = 9 Earth hours
- no moons

THE ONE WITH THE RINGS

- ca 120,000 km (9 x Earth)
- -178 °C
- 100 kg = 107 kg
- 1 year on Saturn = 28 Earth years
- 1 day on Saturn = 11 Earth hours
- 62 moons, 53 of which have been officially confirmed, e.g. **Titan**, **Rhea**, **Iapetus**, **Dione**, **Tethys**

THE WINDY ICE GIANT

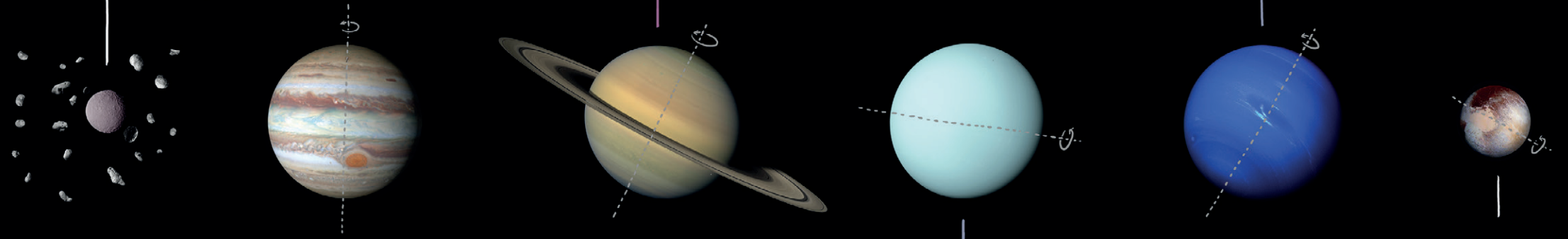
- ca 50,000 km (4 x Earth)
- -214 °C
- 100 kg = 114 kg
- 1 year on Neptune = 165 Earth years
- 1 day on Neptune = ca 16 Earth hours
- 14 moons, 13 of which have been officially confirmed, e.g. **Triton**, **Proteus**, **Nereid**

Gas giants

Ice giants

Kuiper belt

Oort cloud



CERES
414 million km
= 2.8 AU

JUPITER
778 million km
= 5.2 AU

SATURN
1,430 million km
= 9.5 AU

URANUS
2,870 million km
= 19.2 AU

NEPTUNE
4,500 million km
= 30 AU

PLUTO
5,870 million km
= 39.5 AU

THE BIGGEST ONE

- ca 140,000 km (11 x Earth)
- -148 °C
- 100 kg = 253 kg
- 1 year on Jupiter = almost 12 Earth years
- 1 day on Jupiter = 10 Earth hours
- 69 moons, 50 of which have been officially confirmed, e.g. the 4 Galilean moons **Ganymede**, **Callisto**, **Io**, **Europa**

THE TILTED ICE GIANT

- ca 50,000 km (4 x Earth)
- -216 °C
- 100 kg = 91 kg
- 1 year on Uranus = 84 Earth years
- 1 day on Uranus = 17 Earth hours
- 27 moons, named after works of William Shakespeare and Alexander Pope, e.g. **Titania**, **Oberon**, **Umbriel**, **Ariel**, **Miranda**, **Puck**

CLASSIFIED AS A DWARF PLANET

- ca 2,200 km (almost 1/5 Earth)
- ca -230 °C
- 100 kg = 7 kg
- 1 year on Pluto = 248 Earth days
- 1 day on Pluto = ca 6 Earth days
- 5 moons: **Charon**, **Kerberos**, **Nix**, **Hydra**, **Styx**

Illustration not to scale
As at: November 2017

Images: ESA; NASA
Data: NASA

JOURNEY TO THE CENTRE OF MARS

CHRISTIAN LIEBSKE, Senior Scientist in Petrology, conducts high-pressure experiments in which he simulates planetary interiors in a laboratory.

We have been analysing data from space probes for decades, so we have a good understanding of Mars' surface and atmosphere. Its interior, on the other hand, is largely unexplored.

We know that the Martian core is made of **iron**, **nickel** and **sulphur**, but we don't know whether it is solid or liquid. We hope our high-pressure experiments will change that.

Mars Orbiter Mission Mangalyaan (ISRO)

Mars Reconnaissance Orbiter MRO (NASA)

Sojourner Pathfinder Mission (NASA)

Trace Gas Orbiter TGO (ESA)

Opportunity (NASA)

Mars Atmosphere and Volatile Evolution MAVEN (NASA)

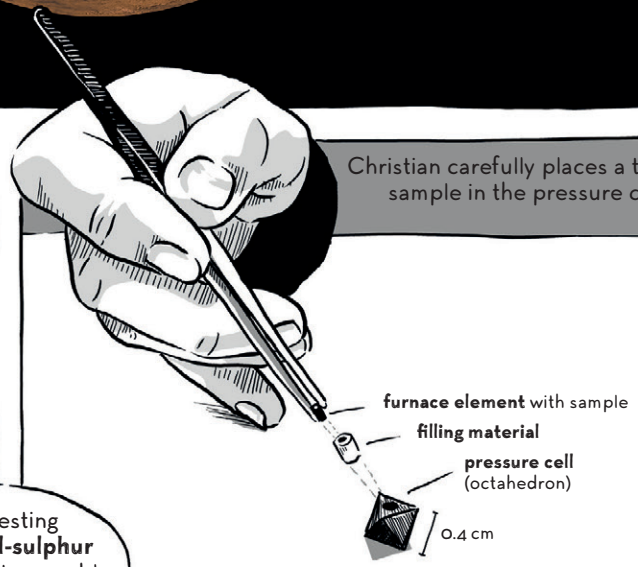
The pressure at the centre of Mars is around 400,000 bar. That equates to the weight of ten trains on a ten centime coin.

The pressure at the centre of Earth, however, is around nine times higher!

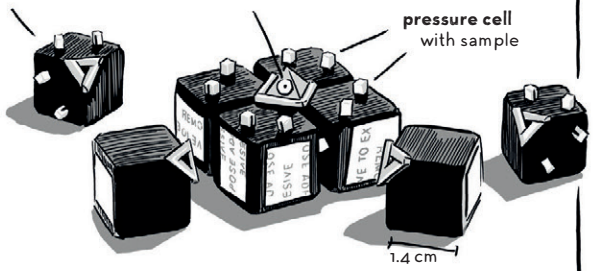
Christian and his colleague Andrew are preparing an experiment that simulates the pressure and temperature in the Martian core.

We're testing **iron-nickel-sulphur** mixtures that resemble the Martian core.

Christian carefully places a tiny sample in the pressure cell.

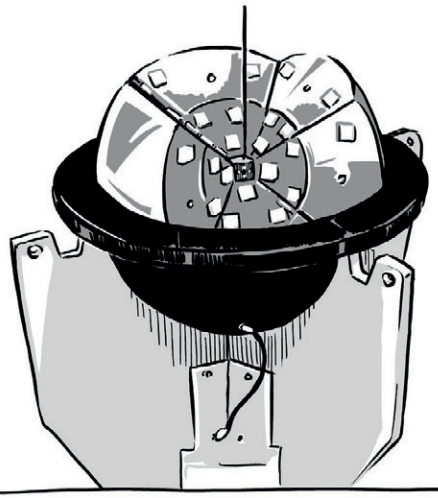


He then places the pressure cell in the centre of eight ultra-hard diamond cubes.

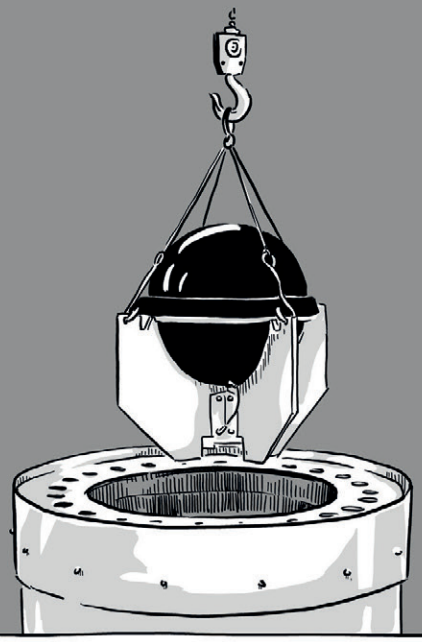


He places the cubes in the centre of a sphere made of six steel wedges...

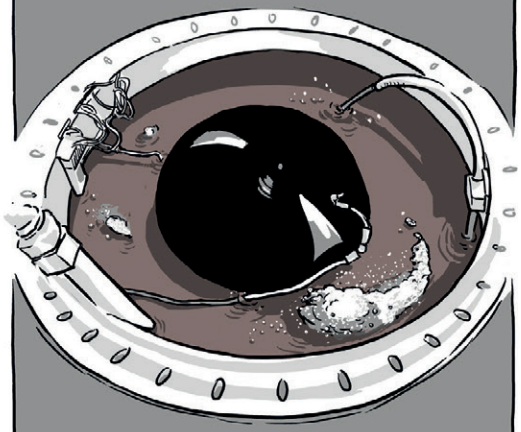
inserted **diamond cubes**



... which is sealed and lowered into the tank.



The tank is filled with hydraulic oil and covered with a lid. The oil pressure is slowly increased and transferred uniformly onto the sample. The sample is then heated.



Some hours or days later, the sample is removed from the completely crushed pressure cell.

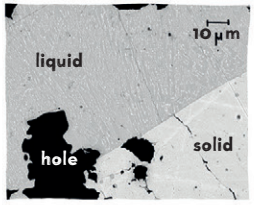
Because the sample was cooled down very quickly, it was 'shock-frozen'. This preserves the state it had in the pressure and temperature inside the tank.

before

after

crushed **sample**

Under an electron microscope we can see the effects of the experiment on the **iron-nickel-sulphur sample**.



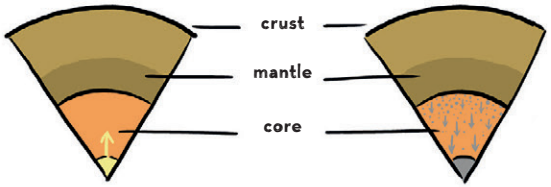
After replicating the Martian core in the lab using different formulas, Christian discusses his findings with his colleague Amir. Amir is collecting chemical and physical data to develop a model of Mars' structure.

Thanks to your calculations, we assume that the Martian core is still largely liquid. Surprisingly it may have a completely different solidification process from that of Earth's core.

HOW THE MARTIAN CORE MAY BE SOLIDIFYING

A) From the inside out:
Like Earth's core, the molten Martian core **crystallises** from the inside outward.

B) From the outside in:
Crystals form at the boundary between the core and the mantle and descend towards the centre, where they gradually build up a solid core **(snowflake model)**.



Solid inner core made of **iron-nickel-sulphur** compounds

Solid inner core made of **iron-nickel** alloy

And which scenario is more likely?

Good question. The truth is probably somewhere in between.

We should learn more in 2019. The **InSight mission** is sure to shed some light on this!

Images: NASA; C. Liebske (modif.)

MESSENGERS FROM SPACE

HENNER BUSEMANN is Senior Scientist in Isotope Geochemistry. He measures noble gases in meteorites, cometary dust and samples from space missions.

On 15 February 2013 a meteor exploded over Chelyabinsk, Russia. The recovered fragments included a meteorite weighing 540 kilograms.

Henner is interviewed by Ivana, a science journalist.

We get lots of questions about the impact in Russia. What exactly are meteorites, anyway?

Meteorites usually come from **asteroids**, which are made of rock and orbit the Sun mainly in the region between Mars and Jupiter called the asteroid belt. When they break apart and the pieces of debris leave the asteroid belt, these pieces are called **meteoroids**.

Asteroids are not to be confused with **comets**. These come from the outer edge of the Solar System and are largely made up of ice and dust.

When a **meteoroid** enters Earth's atmosphere, it's called a meteor.

Friction with the air causes the **meteor** to heat up and begin to glow, a phenomenon we call a **shooting star**.

meteoroid

meteor

shooting star

atmosphere

meteorite

Most meteors burn up completely. However, if fragments do reach the ground, they are called meteorites.

Are all meteorites the same?

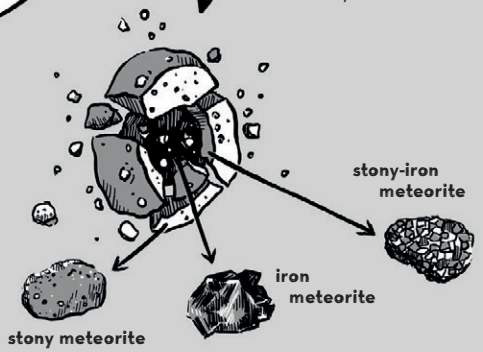
FROM ASTEROIDS TO METEORITES

Early on in the Solar System, asteroids formed and evolved in different ways as time went by.

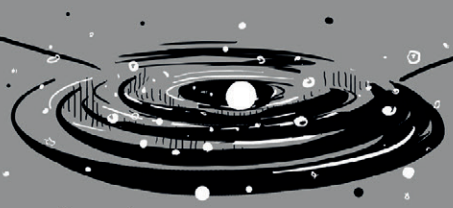
No, each one has its own story to tell.

mantle (rock)
core-mantle boundary
core (iron)

Asteroids that were **heated** developed a layered structure.



DIFFERENTIATED METEORITES



Asteroids break apart during collisions, and their fragments are called meteoroids.

Among the meteoroid fragments that reach Earth's surface, we distinguish between **differentiated** and **undifferentiated** meteorites.

mix of rock and metal

Asteroids that were **not heated** didn't develop a layered structure and have remained chemically unchanged since their formation. They are cosmic time capsules.

chondrite

Let's take a look at a **chondrite** from Chelyabinsk under a microscope.

UNDIFFERENTIATED METEORITES

Wow, it's made up of lots of different components! What exactly do you measure here?

metal-rich inclusion

fine-grained matrix made of rock

0.5 mm

Noble gas isotopes! They tell us whether a rock is extraterrestrial and how long it has travelled through space. This is where we identified this chondrite to be extraterrestrial as well.

In order to be sure where a meteorite comes from, we need to compare it with its parent body. That can only be done with expensive and technically challenging space missions.

Henner working on the mass spectrometer in the noble gas lab.

Have there ever been such missions?

Apollo 12, 1969
NASA

Moon rocks from the Apollo missions later confirmed the origins of **lunar meteorites**.

Viking I, 1975 -1982
Viking II, 1975 -1980
NASA

Curiosity, since 2012
NASA

The Viking lander and the Curiosity rover proved that components of Mars' atmosphere are trapped inside **Martian meteorites**.

Launch of **OSIRIS-REx** on 8 September 2016 from Cape Canaveral, Florida.

And it's lift-off! It's a good thing that I don't have to fly to space in order to study it. The cosmic rays that are so important for my work wouldn't be too good for my health...

Sample-return missions

OSIRIS-REx
Asteroid Bennu
2016 -2023
NASA

Hayabusa I & II
Asteroids Itokawa & Ryugu
2003 -2010 & 2014 -2020
JAXA

Yes, there have: to the Moon, to Mars and to asteroids. Thanks to **Hayabusa I** we were able to analyse a few grains from the asteroid **Itokawa**. Now we are waiting for samples from **Hayabusa II** and **OSIRIS-REx**.

Images: Alex Alishewskikh (Flickr); H. Busemann

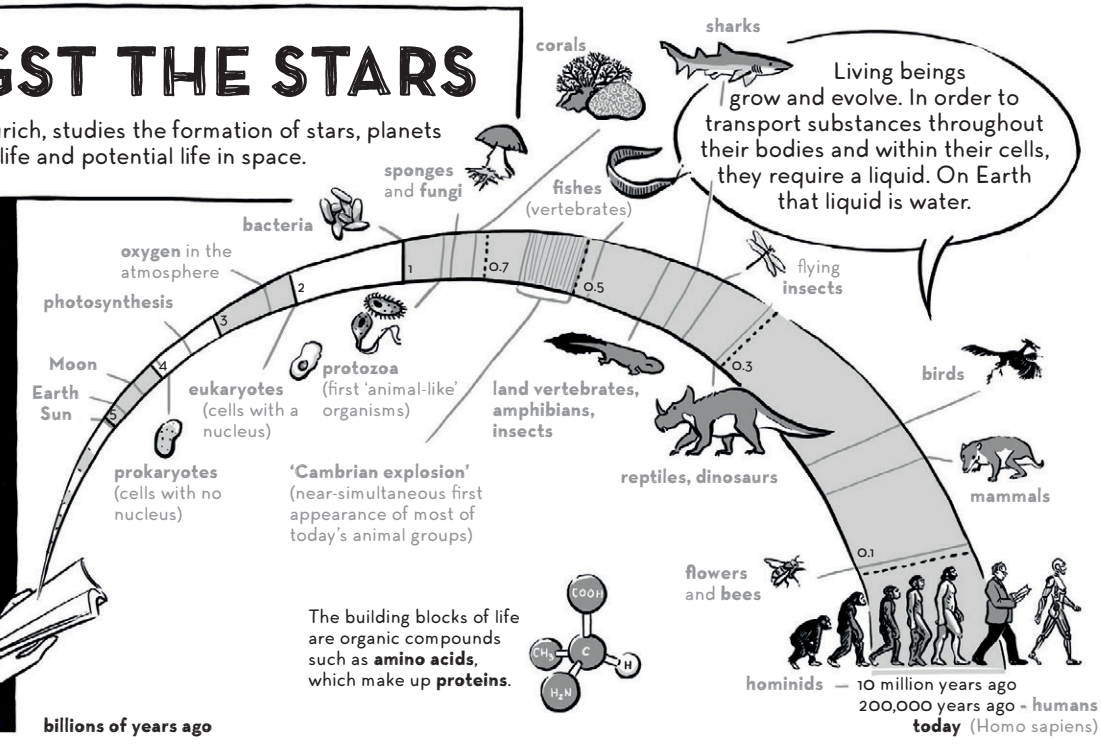
OUT THERE AMONGST THE STARS

BEN MOORE, Professor of Astrophysics at the University of Zurich, studies the formation of stars, planets and galaxies. He is fascinated by the questions of the origin of life and potential life in space.

There are more than ten billion planets in our galaxy alone. Could some of them harbour **life**, like our own planet?

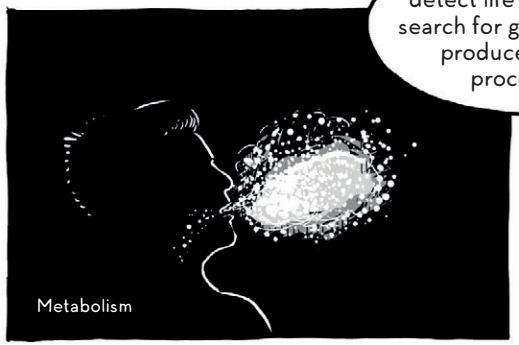
What is life anyway? All life on Earth has common characteristics. It is based on **cells**, carries information in a genetic code and exchanges energy with the environment through **metabolism**.

Living beings grow and evolve. In order to transport substances throughout their bodies and within their cells, they require a liquid. On Earth that liquid is water.



The building blocks of life are organic compounds such as **amino acids**, which make up **proteins**.

In order to detect life in space we search for gases that are produced by life processes.


Metabolism

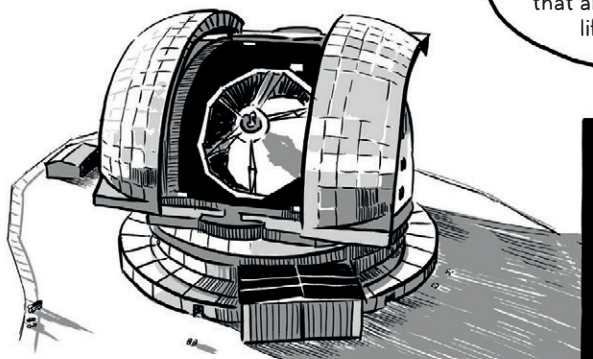

Burning of biogenic substances

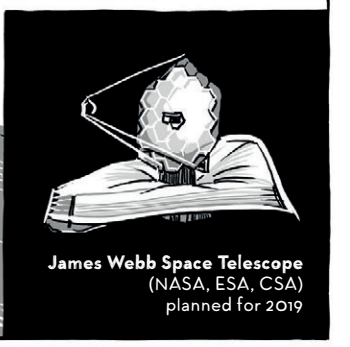

Decay of organic matter


Other gas emissions caused by living beings

Such signs of life on other planets could be measured with the Extremely Large Telescope. It will have a 39-metre-wide mirror, making it the largest telescope in the world.

There are also space telescopes and unmanned space missions that aim to search for life in space.


Extremely Large Telescope (ELT)
at an altitude of more than 3,000 m in Chile's Atacama desert
commissioning planned for 2024


James Webb Space Telescope
(NASA, ESA, CSA)
planned for 2019

These pages have been extracted from a publication accompanying the special exhibition **'Expedition Solar System – Join ETH Zurich on a journey into space'**. The exhibition runs from 28 March 2018 to 16 June 2019 at *focus*Terra, the Earth Science Research and Information Centre of ETH Zurich.

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