Solar system exploration

The Origin and Evolution of the Solar System

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Studying the origin of our own Solar System will lead us to better understand the conditions under which planets similar to the Earth might be formed

The process of studying the Solar System has been underway since primitive peoples first recognized the distinction between the planets, wandering across the skies, and the stationary stars. Our knowledge about the origin of the Sun and the bodies that circle it has been growing ever since. An increasing role in gathering such knowledge has recently been played by space probes. The staff of the PAN Space Research Centre takes active part in the design of such probes.

ESA/AOES Medialab

This artist's impression shows the Rosetta Lander anchored to the comet's surface with instruments, legs and solar panels

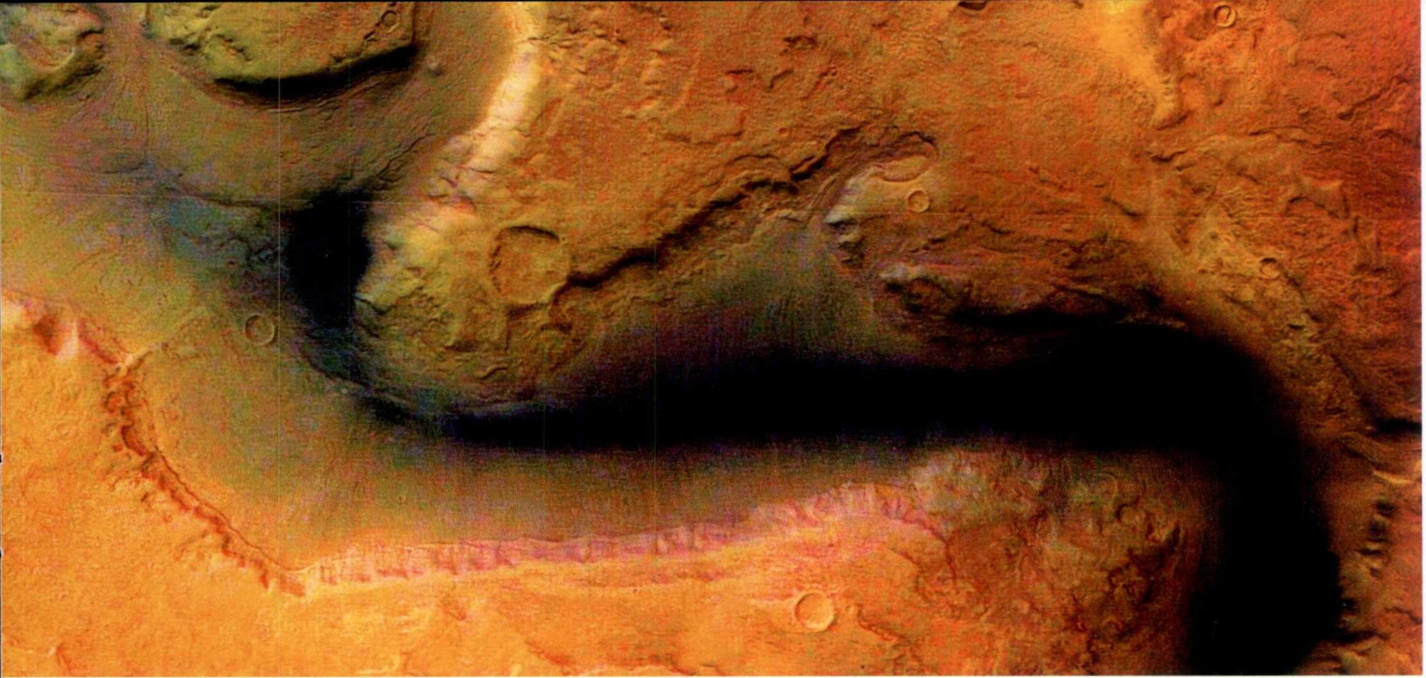
The beginnings

The process of the Solar System's formation was initiated some 4.5 billion years ago, by the self-gravitational collapse of a cloud of interstellar matter, consisting mainly of hydrogen. The coalescence of this rotating gas and dust cloud gave rise to a thickening center, where the formation of the Sun began, and caused the remaining matter to flatten into a so-called proto-planetary disk. When the temperature within this central aggregation, still thickening and increasing its mass, rose to about one million degrees, nuclear reactions began to take place, changing hydrogen into helium, and a very productive source of energy thus appeared.

When the original cloud, rotating ever more rapidly, took on the shape of a disk with a central aggregation, the dust grains became focused into a plane perpendicular to the axis of rotation. This caused more frequent collisions among them, leading individual specks to conglomerate into larger lumps. The composition of such lumps depended upon the region of their formation: closest to the Sun, where the temperature was highest, the grains were devoid of gaseous substances and mostly composed of refractory metals and silicates. Further away, in areas with a lower temperature, they could be covered by a layer of icy water or carbon dioxide, and even further away by methane and ammonium. The force of the individual lumps' mutual gravitational pull gave rise to more agglomerations, leading to the further growth of ever-larger lumps. After a few million years, they formed a number of clearly focused centers, called proto-planets, which gathered in more and more matter from their vicinity.

The formation of planets

Four proto-planets emerged in the vicinity of the Sun, and through a relatively long process of accretion and stratification, lasting on the order of 100 million years, they became the planets of the terrestrial group (Mercury, Venus, Earth, and Mars). These are rocky-metallic bodies with average densities within the range of 3.9-5.5 g/cm^3. Another four proto-planets emerged in colder areas further away from the Sun, starting the process of accretion and stratification that gave rise to the Jovian planets (Jupiter, Saturn, Uranus, and Neptune). These are called "gas giants," as they mainly consist of hydrogen and helium;



ESA/DLR/FU Berlin (G. Neukum)

This picture was taken by the ESA's Mars Express orbiter from a height of 273 km. The area is 100 km across, and shows a channel (Reull Vallis) once formed by flowing water. The Space Research Centre is involved in developing one of the Mars Express instruments: the PFS (Planetary Fourier Spectrometer) experiment will determine the chemical composition of the surface and the atmosphere of Mars

their diameters are from 4 to 11 times larger than Earth's and their average density is in the range of 0.7-1.6 g/cm^3. The temperatures in the regions where they formed were so low that it was possible for water ice, as well as frozen carbon dioxide, methane, and ammonium, to survive and condense. The abundance of icy substances made the accretion process more productive, partly as a result of icy planetesimals' greater tendency to stick together. The rapidly increasing masses of these planets meant that they also drew in more and more gas from their vicinity.

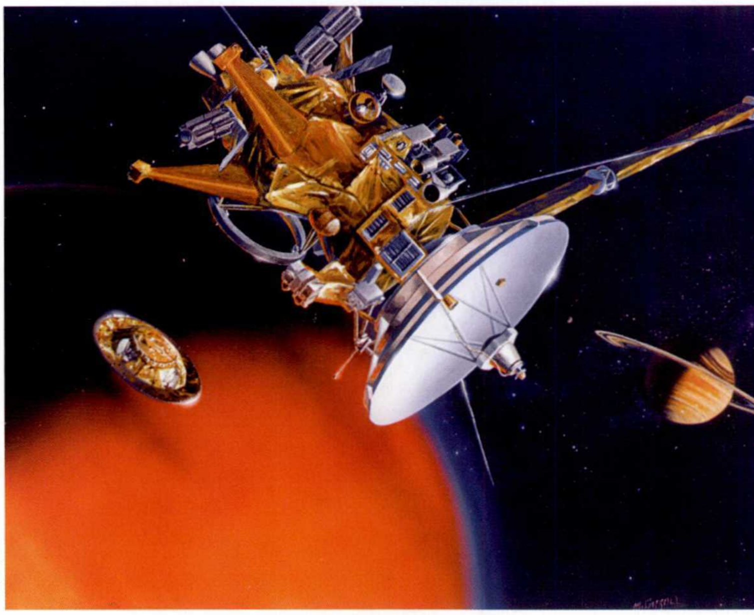
Cosmic cleanup

The final stage of the Solar System's formation resembled a construction site being cleared of leftover building materials. An important role in this process was played by the Sun, which was particularly active during the initial phase of its evolution, casting off huge quantities of matter in the form of the so-called solar wind. Within the course of less than one million years, the initial gusts of this wind, which were significantly stronger than those observed today, dispersed the gas and dust that remained uncondensed in interplanetary space. Another factor that contributed to the cleanup of the Solar System was the gravitational pull of the increasingly more massive planets, mainly of the largest ones, Jupiter and Saturn. It was probably they that caused a large portion of the remaining planetesimals, which had avoided being absorbed by proto-planets or falling onto already formed planets, to be expelled far outside the area of the planets' orbits. Today these leftover planetary building materials probably orbit the Sun at distances tens of thousands of times farther than the Earth; they form the so-called Oort Cloud. Jupiter's gravitational influence is also responsible for imprisoning planetesimals between the orbits of Mars and Jupiter, where no planet successfully formed. Today the remnants of these make up the main belt of asteroids, or minor planets, discovered more than 200 years ago, orbiting the Sun at 2 to 4 times the Earth's distance.

> Pluto, until recently considered to be the 9th planet of the Solar System, actually appears to be one of the members of the Kuiper Belt

These processes by which leftover material from the Solar System's formation was removed by the solar wind and gravitational influence did not affect the planetesimals that remained on the edges of the proto-planetary disk; today they make up a second belt of asteroids, the so-called Kuiper Belt. The objects in this belt, which have only been observed for 10 years, revolve the Sun at distances at least 30 times farther than the Earth.

A secondary effect of this cleaning and ordering process was the so-called great bombardment, whose traces have



NASA/JPL/Caltech

In January 2005 the Huygens probe will be dropped from the Cassini satellite to settle on Titan's surface. SRC is participating in the mission

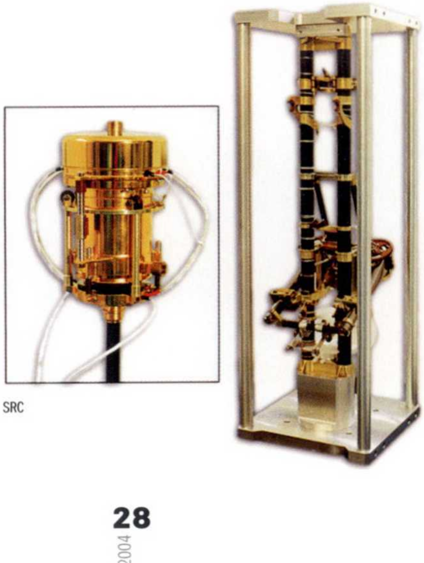
survived to this day on many bodies in the Solar System. The traces of such collisions can be seen today particularly clearly on Mercury and the Earth's Moon, which have no atmosphere, as well as on many other bodies with a stable surface. All these violent processes slowly subsided more or less 4 billion years ago, and since that time the Solar System seems to have been evolving without any global-scale shocks.

Cosmic leftovers and fragments

One distinctive aspect of the Solar System's evolution seems to be a kind of slow drift toward the Sun of material that was originally expelled outward from it. This explains the current existence of objects whose lifetime is significantly shorter than the age of the Solar System. The most interesting of these are comets - small icy chunks that become enwreathed by huge clouds of gas and dust when they draw closer to the Sun, as a result of which they are sometimes visible from the Earth. The hypothetical Oort Cloud is the most probable source of comets, which move around the Sun along almost parabolic orbits. The mechanism that sends objects from the Oort Cloud toward the Sun involves galactic tidal forces, as well as the gravitational effects of nearby stars or some sort of massive clouds of interstellar matter. Short-period comets are thought to originate from the Kuiper Belt.

Developing methods of identifying the so-called collision orbits of objects considered to be potentially dangerous to the Earth represents an original Polish contribution toward our understanding of this extremely important problem

Studying the process of this diffusion and the particularities of its individual stages seems to be one of the most interesting topics in Solar System research today. The most important subjects in this regard include identifying the trajectories of comets and various non-standard asteroids, and analyzing their dynamic evolution - and on these issues, Polish astronomers have also been making a significant contribution. The PAN Space Research Centre has specifically developed methods and computer software that make it possible for the orbits of comets and asteroids to be calculated with the greatest precision that can be obtained from the available observational data.



SRC

The Space Research Centre is participating in Rosetta experiment MUPUS, involving a penetrator of the cometary nucleus. Left: the penetrator hammering device, right: the penetrator deployment device

NASA/JPL/Caltech

An artist's impression of the Rosetta orbiter and lander approaching comet 67P/Churyumov-Gerasimenko

Probing the solar system

The most spectacular direction of Solar System research today, one that now absorbs the greatest share of energy and funding, involves sending probes to study planets, comets, and asteroids. One of these we should mention is the European Space Agency's Mars-Express probe, carrying on board an apparatus (a Fourier spectrometer for the spectral analysis of radiation reflected and emitted by Mars' atmosphere and surface) which was partially built by Polish scientists and engineers. The Cassini probe, launched in 1997, will initiate analogous studies of Saturn in 2004. The Huygens probe, which will detach from Cassini in order to land on the surface of Titan, Saturn's largest moon with an atmosphere similar to Earth's, includes a temperature and thermal conductivity sensor built in Poland. And finally, the cometary probe Rosetta, launched at the beginning of 2004, will study a typical short-period comet, using a penetrator designed and built in Poland, which will pierce through the comet's probably icy surface into its core. All of these instruments were created at the PAN Space Research Centre, the only institution in Poland that deals exclusively with issues related to the exploration of space - putting the Centre amongst the world's significant participants in contemporary Solar System research. ■

Further reading:

Sitarski, G. (1999). How to Find an Impact Orbit for the Earth-Asteroid Collision, *Acta Astronomica, 49,* 421-431.

Wood, J. A.(1999) Forging the Planets: The Origin of Our Solar System, *Sky and Telescope, 97-1,* 36-48.

Yeomans D. K. (2000) Small Bodies of the Solar System, *Nature, 404,* 829-832.