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PROPOSAL FOR AN INTEGRATED EUROPEAN SPACE EXPLORATION STRATEGY

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ABSTRACT

Recently, in his vision for space exploration, US president Bush announced to extend human presence across the solar system, starting with a human return to the Moon as early as 2015 in preparation for human exploration of Mars and other destinations. In Europe, an exploration program, termed AURORA, was established by ESA in 2001 – funded on a voluntary basis by ESA member states – with a clear focus on Mars and the ultimate goal of landing humans on Mars around 2030 in international cooperation. In 2003, a Human Spaceflight Vision Group was appointed by ESA with the task to develop a vision for the role of human spaceflight during the next quarter of the century. The resulting vision focused on a European-led lunar exploration initiative as part of a multi-decade, international effort to strengthen European identity and economy. After a review of the situation in Europe concerning space exploration, the paper outlines an approach for a consistent positioning of exploration within the existing European space programs, identifies destinations, and develops corresponding scenarios for an integrated strategy, starting with robotic missions to the Moon, Mars, and near-Earth asteroids. The interests of the European planetary in-situ science community, which recently met at DLR Cologne, are considered. Potential robotic lunar missions comprise polar landings to search for frozen volatiles and a sample return. For Mars, the implementation of a modest robotic landing mission in 2009 to demonstrate the capability for landing and prepare more ambitious and complex missions is discussed. For near-Earth asteroid exploration, a low-cost in-situ technology demonstration mission could yield important results. All proposed scenarios offer excellent science and could therefore create synergies between ESA's mandatory and optional programs in the area of planetary science and exploration. The paper intents to stimulate the European discussion on space exploration and reflects the personal view of the authors.

INTRODUCTION AND BACKGROUND

The first Space Exploration Initiative, with the long-term goal of human missions to the Moon and Mars, was announced in 1989 by US president George Bush (sen.). In Europe, ESA launched the Lunar Exploration Initiative in 1994 at the International Lunar Workshop in Beatenberg, Switzerland, aiming at the robotic and eventual human exploration of the Moon. Both initiatives passed away in the years afterwards, mainly due to lack of funding and a concentration on the build-up and operation of the International Space Station (ISS). A reincarnation of the exploration initiatives, however, can be observed today in the US and Europe.

What is Space Exploration?

Science and exploration both have their origin in the human curiosity and desire to understand the world around us, which is one of the driving forces for the cultural evolution and prosperity of mankind. Obviously, the exploration idea has its roots in the exploration and colonization of our Earth, including its many inhospitable regions. The history of humankind shows that societies and individuals need challenges to advance, otherwise they stagnate and decay in the long run. An impressive example is the decay of the Ming Empire of China, which around 1400 AD was the most powerful and knowledgeable nation on Earth. Their advanced ships had explored the oceans up to the

east coast of Africa and were about to discover Europe, when all activities were stopped by the Confucian bureaucrats because they were deemed useless. Another driving force for scientific and technological progress is war, but it is hoped that humankind is on the verge to overcome this inhumane threat.
Space exploration aims at expanding the present frontiers for human access to the solar system and beyond (both via robots and humans), relying on human experience and involvement and creating emotions and exceptional public interest (Fig. 1). The objective is to look for unknown and fascinating phenomena (incl. landscapes not previously encountered, search for life, etc.), raising new scientific questions, or opening up new fields of applications and commercial utilization (e.g. in-situ resources, tourism). Exploration of space is particularly demanding, since it involves hostile environments and requires sophisticated and thus expensive technologies. Therefore, it should be achieved stepwise: initially by robots, substituting humans and transmitting their findings to Earth (with all the resulting limitations), and later by human presence. This approach seems reasonable in order to prepare and validate the necessary technologies, and to find out the landing sites most interesting for detailed studies by humans. In fact, it has been chosen in the frame of the Apollo Moon landings and is currently pursued in NASA's Mars exploration program.

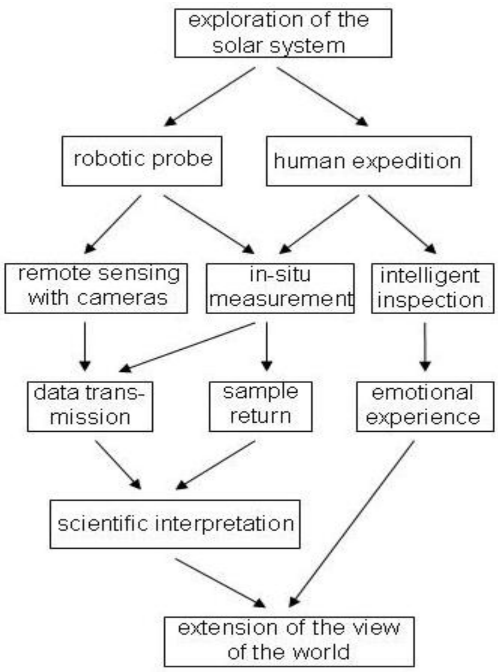

Fig. 1: Robotic and human exploration

In this approach, missions like Pathfinder and Mars Exploration Rover (MER), which are also spectacular as stand-alone planetary science missions, can be considered as precursors for human landings. Within the foreseeable future, robots can not fully replace humans who are able to react flexibly and make decisions in unexpected situations. On Earth, for example, it is unimaginable that geologic field exploration could be done without humans. It should be kept in mind, however, that human missions may comprise more than just science and technology driven rationales, e.g., philosophical, ethical, and political aspects.

Why space exploration now?

After the Apollo program, human spaceflight has concentrated for the last three decades exclusively on missions to Earth orbit with the development of transportation systems and orbital infrastructures. The built up of the ISS will hopefully soon be finished and its capacities fully utilized. Research on the ISS is mostly dedicated to life sciences and – to a smaller extent – material sciences. Though a strong effort is under way to derive terrestrial applications, a clear emphasis of ISS-related research is towards developing means that enable long duration human presence in space. Since staying with astronauts in Earth orbit for decades undermines public and political support and will soon be a dead end for human spaceflight, the policy should be to expand human spaceflight beyond Earth orbit with the ISS as the springboard, this also in view of the European competitiveness and industrial experience gained during several decades of human spaceflight, which would otherwise be endangered or lost. It's time now to identify new objectives and challenges for the years to come.

US Approach

NASA takes a very pragmatic approach to space exploration with the goal to "implement a sustained and affordable human and robotic program to explore the solar system and beyond". In his new vision for space exploration, US president George W. Bush (jun.) announced in January 2004 to extend human presence across the solar system, starting with a human return to the Moon as early as 2015 in preparation for human exploration of Mars and other destinations. A series of robotic missions to the Moon will be initiated no later than 2008 – with the Lunar Reconnaissance Orbiter as the first step – to prepare for future human activities, together with a parallel robotic program for Mars.

The Situation in Europe

In Europe, the discussion of the role of humans versus robots in space is still controversial and the distinction between robotic and human space programs is much more pronounced than in the US. ESA's space programs are organized in two main categories: mandatory and optional. In the first case, all ESA member states have to contribute to an approved program according to their gross national product ratio, in the second case, the member states are free to participate individually with an arbitrary percentage. The space science program is mandatory. It covers projects in the field of science of the universe, including astronomy and solar system research. Up to now, it is exclusively robotic. Several other programs related to human spaceflight exist, which are optional and can be summarized as ISS programs, e.g., ISS exploitation and European program for Life & Physical Sciences (ELIPS). Microgravity research forms the basis for ELIPS, where physical sciences include material sciences, fluid physics, and fundamental physics. Today, physical sciences may be more generally characterized by physics and engineering in variable gravitational environments (compare Table 1).

ISS	~10^{-6} g
NEAs	< 10^{-5} g
Moon	0.16 g
Mars	0.38 g
Earth	1 g
Jupiter	2.64 g

Table 1: Different gravity levels compared to Earth's surface (g = 9.81 m/s^2)

In 2001, a dedicated exploration program, termed AURORA, was established by ESA – recently renamed European Space Exploration Program (ESEP) – with a clear focus on Mars and the ultimate goal of landing humans there around 2030 in international cooperation [1]. Given the very modest or even lacking experience with planetary missions in Europe until just a few years ago, AURORA was principally aiming at preparing European space industry for meaningful contributions to an international planetary exploration program as a system-level partner, providing critical mission elements rather than subsystems or instrumentation. Two European-led robotic missions to the surface of Mars were proposed in the context of AURORA: a mission focused on exobiology, ExoMars, based on a rover about the size of the MER vehicles, and a Mars Sample Return (MSR) mission, with the latter being considered as a potential cooperative effort with NASA. Included was also the option of technology demonstrations on the Moon, but no dedicated missions were identified. AURORA was conceived as a separate optional program and did not find adequate support and funding from all European member states. It was even claimed by some governments that a specific program for exploration should not be established because it is already covered by the mandatory space science program. The budget and planning of that program, however, does not allow significant exploration activities for the coming decade. The only approved future planetary science missions are Venus Express and the Mercury mission BepiColombo, which are both limited to orbiters. Concerning ongoing missions, SMART 1 – mainly a technology demonstrator for electric propulsion – is on its way to lunar orbit and – except for the Titan probe Huygens and Rosetta's comet lander Philae – there is no further in-situ science planned on planetary surfaces in the space science program.

At the recent ESA Council meeting in March 2004, an ESA long-term plan for 2004 to 2013 was proposed with three new initiatives, one of them being exploration oriented and termed Inspiration Initiative [2]. Main contents for the coming years would be robotic missions, exploration technologies, and scientific support, with the overall guiding principle to "find, understand, sustain, and expand life". The estimated budget for the period 2005 to 2013 was in the order of 1 billion Euro. For 2004/05, a preparatory phase – termed European Space Exploration Program (ESEP) – was approved in July 04 by AURORA-participants. The final proposal to be co-financed by ESA member states and the European Union (EU) will be presented at the 2005 Ministerial Council.

In the White Paper of the EU [3] *"Space: a new European frontier for an expanding Union"* the increasing strategic importance of space and space policy for the EU was emphasized, including the option for additional joint ESA-EU funding. Besides space science, also space exploration was mentioned as a separate promising topic to be further assessed .

In 2003, a Human Spaceflight Vision Group was appointed by ESA with the task to develop a vision for the role of human spaceflight during the next quarter of the century. The resulting vision focused on a European-led lunar exploration initiative as part of a multi-decade international effort to strengthen European identity and economy [4]. This vision needs to be worked out in more detail, especially with respect to a robotic precursor program. It must be kept in mind that up to now Europe/ESA has not successfully landed on a planetary body, the ill-fated Mars Beagle 2 lander having been the first attempt.
Corresponding to the above mentioned developments, ESA appointed a new director for exploration who will lead the unified directorate of Human Spaceflight, Microgravity and Exploration Programs, starting November 04.

SPACE EXPLORATION – AN INTERDISCIPLINARY APPROACH

In order to develop a consistent European exploration strategy, space exploration is first placed within the context of the existing European space programs, outlining its objectives with respect to the classical disciplines of space research. Fig. 2 shows how space exploration may be positioned as a well defined interdisciplinary and application oriented self-contained research area.

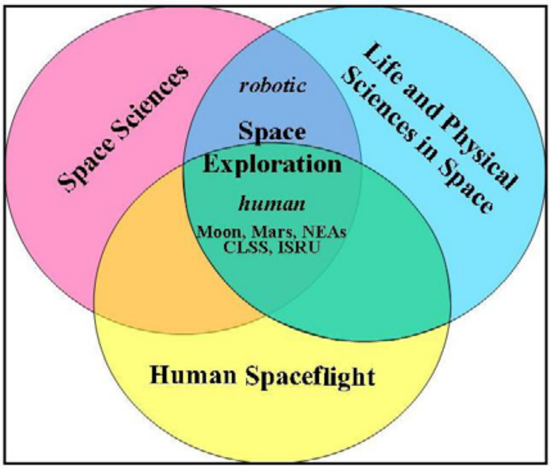

Fig.2: Exploration – interdisciplinary area of research

On the one hand, there are the science disciplines space sciences and life and physical sciences in space, which interact and overlap in many areas like search for life and search for exo-planets. On the other hand, there is the engineering discipline of human spaceflight which also overlaps with the science disciplines. Research with the Hubble Space Telescope and on board the ISS are just a few examples. Now, space exploration may be characterized by the domain, as shown in Fig. 2, where all three disciplines intersect and overlap (human part), together with the area just above it (robotic part). The research would be driven by the goal to expand human access to our solar system and – at least ultimately – have humans right in place. Space exploration activities would in the first place focus on the potentially "habitable zone" around the sun, enclosing Earth's orbit, the Moon, Mars, and near-Earth Asteroids (NEAs) [5]. Later on, also the main asteroid belt and the moons of Jupiter may be included. Besides geosciences, life sciences, and exobiology, also engineering fields like closed life support systems (CLSS), artificial ecosystems, in-situ resources utilization (ISRU), and materials production would be addressed. More details are given in Table 2, but the list is not exhaustive.

Space Exploration Research Fields	including
Geosciences	characterization of planetary (sub)surfaces, atmospheres, and radiation environments (e.g. using. in-situ experiments)
Life sciences and exobiology	habitat, CLSS, artificial ecosystems, search for life
Astronomy	e.g. telescopes on the Moon
Physical sciences and processing	*in-situ* resources utilization (ISRU) and materials production
Advanced power and propulsion	high power for electric propulsion, base supply and ISRU
Entry, descent, landing, Earth return	sample return and human mission applications
Mobility on, below and above planetary surfaces	sampling devices, robotic & human surface transportation systems
Intelligent robotics and virtual reality	autonomous exploration, substitution of human capabilities
Simulation in terrestrial laboratories and facilities	artificial/planetary environments and habitats
Autonomous data collection and control	intelligent operations & control for robotic outposts and human missions
Mission analysis and optimization	spacecraft and trajectory design

Table 2: Major fields of research for exploration (science & technology)

Clearly, exploration requires interdisciplinary research and extends pure science in that it is technology and application oriented. In the long run, this approach will lead to a better and more complete understanding of the processes and environmental conditions prevailing in space and their consequences for the human species, including potential threats and countermeasures. A recommended approach for the future would be to leave the responsibility for purely science driven missions including solar system research in ESA's mandatory space science program – extended by a corresponding life and physical sciences program – and accomplish all missions focusing on robotic and eventual human exploration of the Moon, Mars and NEAs within an interdisciplinary optional program for space exploration to be strongly supported by all ESA member states.

DESTINATIONS FOR EXPLORATION

As outlined above, the relevant destinations for the next exploration activities are the Moon, Mars, and NEAs [6,7].

Why the Moon?

The Moon is very close to Earth and might be used as its natural spaceport. The poles with nearly permanently illuminated regions and permanently shadowed areas close-by are particularly attractive as future landing sites (Fig.3).

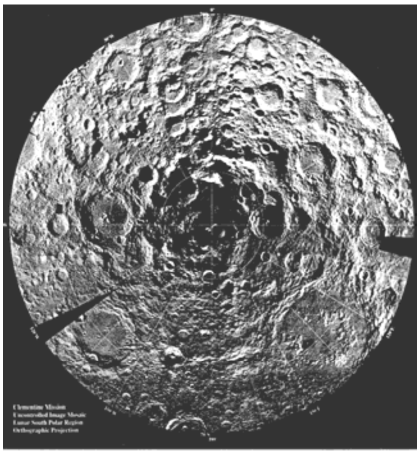

Fig.3: Lunar south pole (imaged by Clementine)

Volatile deposits in cold traps at both lunar poles have been postulated since the early 1960's as a consequence of cometary impacts, and previous orbiting missions have provided indications for them [8,9]. The clarification as to whether they really exist is considered to be a significant objective in future planetary exploration for several reasons: if existing, they would provide a unique opportunity to study the isotopic composition of cometary ices and any stratigraphy in them would give information on the time history of cometary impacts in the Earth-Moon system, further on they would provide a valuable resource for future manned operations on the Moon.

Lunar exploration would comprise

a) science of/on/from the Moon, i.e.: origin and evolution of the Earth-Moon and planetary system and of the sun (trapped solar wind), life sciences under hostile conditions (incl. CLLS), telescopes in permanently shaded polar regions and on the far-side (for infrared and low-frequency radio astronomy) [10].

b) resources identification and utilization, i.e.: presence of water ice in permanently shaded regions at the poles, oxygen from regolith, materials production from in-situ resources (ores?) [11,12,13].

c) technology demonstrations for more distant exploration, i.e.: transportation and surface infrastructures, e.g., lander, rover, hopper, habitat, CLSS.

Why Mars?

Mars is the most Earth-like planet. Its atmosphere is composed mostly of CO_2 and there is plenty of H_2O (parts of it in liquid form – at least at some time in the past). It is the preferred destination for human missions in the coming decades, and the scientific research comprises the fascinating goals to search for life – fossil or still existing – and to understand planetary formation and evolution (interior structure, history of the atmosphere, climatic changes, etc.). To enable longer-term human presence, the development of artificial ecosystems and exploitation of in-situ resources is mandatory, as well as the knowledge of the surface radiation environment [14,15]. Surface mobility and access to subsurface regions will be important for science and information on the resources inventory (search for life, sedimentary layers, ground reservoirs of water, etc.)

Why NEAs?

Most of the asteroids are in some sense the fossils of the solar system. Especially the undifferentiated primitive C type asteroids are expected to hold key information for the origin and formation of the solar system and life on Earth, since they have – unlike the planets – undergone little alteration and, thus, represent most closely the properties of the primordial solar nebula. In addition, many of them contain interesting resources (e.g. water) for further exploitation. Therefore, they are highly inter-

esting for exploration. Although a large amount of asteroid samples exists on Earth as meteorites, many questions are yet unresolved because the linkage between asteroids and meteoritic samples is not yet completely understood.
Near-Earth objects are asteroids and short-period comets with orbits that intersect or pass near the orbit of Earth. The largest of them with more than 1 km in diameter (about 1000 objects [16]) pose a significant hazard to human civilization and to life on Earth. Even objects that do not intersect the orbit of Earth may evolve into Earth-crossers, since their orbits are chaotic, having a relatively short dynamical lifetime of about 10^7 years [17]. One day, it might become necessary to prevent a specific object from impacting Earth by nudging it out of its orbit. To be able to do this, we must determine their bulk properties as soon as possible.

What else?

Further destinations for (robotic and human) exploration beyond Mars in the future are the asteroids in the main belt and the moons of the giant planets.
To realize the ultimate dream of exploring other planetary systems, more than a breakthrough or revolution in power and propulsion technology would be needed. This would probably require spacecraft speeds close to the velocity of light.

INITIAL ROBOTIC EXPLORATION

The two planned robotic AURORA flagship missions – ExoMars and MSR – are rather ambitious, complex missions. They are quite risky, considering that Europe/ESA has not yet performed a successful landing on a planetary body. It appears indispensable to develop and demonstrate safe landing technologies beforehand by smaller missions, satisfying in parallel significant scientific objectives. In this context, the question which landing technologies should be developed is very important. A controlled soft landing is indispensable for larger future missions like sample returns from the Moon and Mars and eventual human expeditions, while semi-hard airbag technologies – as developed for Europe's first but ill-fated Beagle 2 lander and demonstrated by Russia on the Moon (Fig.4) and NASA/JPL on Mars – are useful for smaller and cheaper missions.

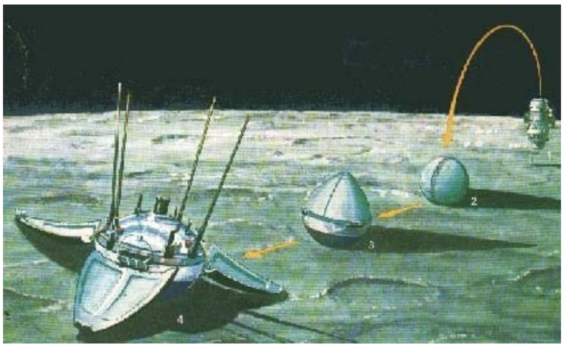

Fig.4: Semi-hard lunar landing
(Soviet LUNA 9 and 13, 1966)

In 2004, the German Aerospace Center (DLR) invited the European planetary in-situ science community to participate in two workshops at Cologne with the objective to discuss the future of planetary surface exploration. About 80 scientists from all over Europe participated and analyzed options for future lander missions in three working groups, focusing on robotic exploration of the Moon, Mars, and NEAs. The corresponding short reports submitted to ESA describe

- a roadmap for future lunar exploration
- a multi-site lander mission to Mars, complementary to the planned ExoMars project
- a proposal for a low-cost lander mission to a near-Earth asteroid.

In addition a resolution and a recommendation from the participating scientists were formulated, stating that

- in-situ science is extremely promising and important to understand the formation and evolution of the solar system and, particularly, our Earth including life.
- without new missions outstanding expertise for in-situ experiments and corresponding technology in Europe is endangered.
- ESA should study and implement a planetary in-situ science and technology program, be it in the frame of the mandatory science or optional exploration activities.
- the scientific institutes offer to try to find substantial support by internal contributions for payloads and system components to reduce costs to ESA.

Considering these proposals, the following scenarios for an initial robotic exploration phase can be identified:

Robotic Lunar Exploration

A reasonable roadmap could consist of:

Step 1 (around 2008): Small-scale landers to be dispatched into the identified shadowed depressions near the north or south pole (Fig.3). This should be harmonized with international partners, because several landing sites must be investigated [18]. The envisaged concept is based on a semi-hard lander design with separable airbags similar to the Soviet LUNA 9 and LUNA 13 landing technique which is compatible with the unknown morphology (Figs. 4 and 5). Landing inside the depressions is considered more robust and reliable than attempting access from an illuminated landing site by, e.g., a large rover. A battery-powered short duration mission will be performed, based on a self-penetrating mole to provide access into the regolith down to several meters. A suite of sensor heads would be designed to detect volatiles in-situ, and a relay satellite will be required for data transmission to Earth [19]. Technological experience from this mission could also pave the way to other destinations.

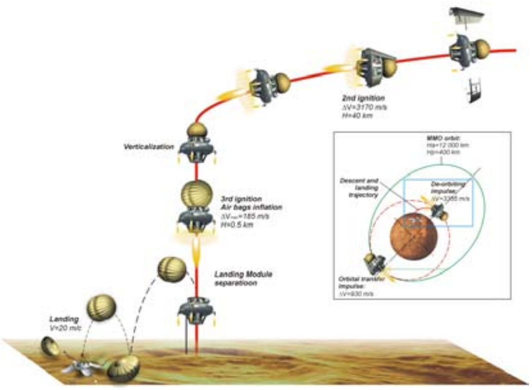

Fig.5: Airbag landing scenario for Mercury or the Moon (Babakin study June 2003, ESA)

Step 2 (around 2010-2012): A technically more challenging lunar south pole mission with a controlled soft landing (on legs) at the top of the peak of (quasi) eternal light. An instrumented rover as payload would address science, exploration and ISRU technology. The lander design could be updated from the EUROMOON study [20], integrating new knowledge from SMART-1 and other lunar missions, and would demonstrate European capabilities for controlled soft landing and surface mobility (Fig. 6).

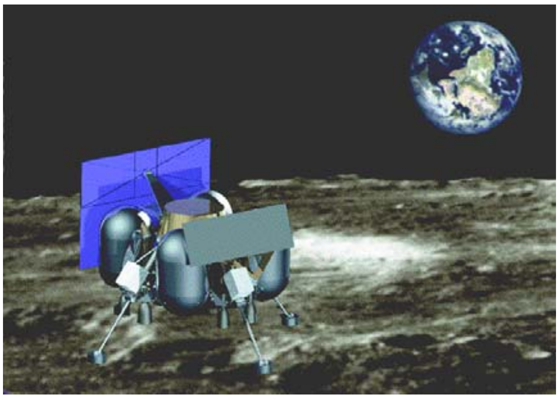

Fig.6: Artist's view of EUROMOON (ESA)

Step 3 (beyond 2012): A mission even more complex with a rover and sample return. Landing site could be, e.g., the pole or the south pole Aitken-basin (access to rocks from the lunar mantle). This mission would demonstrate European Earth return capability. Cooperation with partners (such as US, Japan, China) should be envisaged, because a representative set of samples from several landing sites is desired, especially from the lunar backside.

Robotic Mars Exploration

The implementation of a modest Mars landing mission before ExoMars and MSR would not only demonstrate ESA's capability to land successfully on Mars but also address science objectives not covered by existing or planned missions and recover those not achieved by several failed and/or cancelled missions.

Unique Mars science, consistently ranked with high priority but not yet implemented in the NASA Mars Exploration Program, is a Mars geophysical and meteorological network. It addresses the planet's internal structure – with important clues to Mars' evolution and the history of its magnetic field – and its atmospheric circulation patterns – with impacts on climate evolution and volatile cycles. In fact, a Mars network mission, consisting of several landers operating simultaneously at different sites, has been repeatedly studied to Phase A – and, partially, Phase B - level in Europe, along with significant interest from the US side. Some aspects of Mars network science were already lost in the launch failure of the Russian/European MARS 96 mission.

Other unique Mars science that was lost were the objectives of the Beagle 2 lander of ESA's Mars Express mission which attempted to conduct novel in-situ investigations on organic species in subsurface regolith and rock samples to address the issue of possible chemical traces

of early Martian biota that would have been preserved in regimes protected from the modern, adverse surface conditions [21].
Correspondingly, efforts are under way within ESA, the European planetary science community and the Beagle 2 team to define a modest Mars landing mission for the 2009 opportunity which may formally be considered the first part of a redefined two-launch ExoMars scenario. The launch in 09 would carry an orbiter with either one 200 kg class or two 100 kg class landers to Mars which would utilize a so-called 'deadbeat' airbag system for final impact damping – as it is planned for the rover carrying ExoMars descent module (in contrast to the traditional bouncing airbags used thus far). This way, the 09 lander would prepare technology for the larger lander carrying the ExoMars rover on the second launch in 2011 (Fig.7).

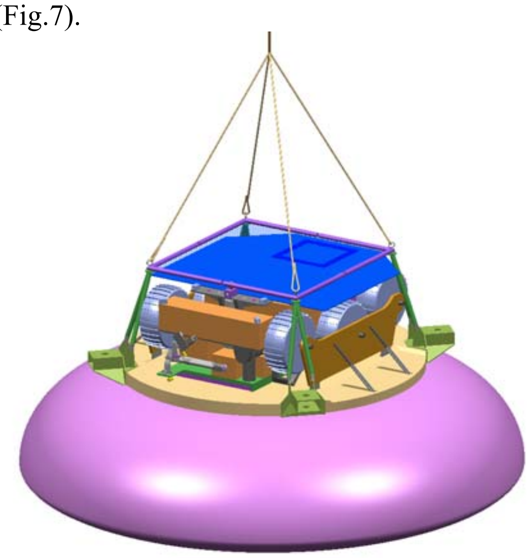

Fig.7: View of ExoMars rover on descent module with inflated 'deadbeat' airbag and parachute attachment (Astrium UK concept).

If the two-lander option is chosen for the 09 mission, multi-site science and thus aspects of the Mars geophysical and meteorological network can be implemented, in addition to a reflight of at least most elements of the unique Beagle 2 payload. This would still be in time in terms of scientific relevance w.r.t. NASA's Mars missions planned for the same time frame. Such combined science objectives for an 09 landing mission become feasible through the higher payload mass offered by the envisaged lander concept as opposed to the smaller Beagle 2 and dedicated network lander designs.

Robotic NEAs Exploration

Unlike their parent bodies in the asteroid belt, some near-Earth objects are the most readily accessible extraterrestrial bodies. The energy requirement to rendezvous with some of them is less than to land on the Moon's surface. Therefore, they are ideal targets for technology demonstration missions.
In the report from the in-situ science workshop at DLR a mission to rendezvous a binary C type near-Earth asteroid (1996FG3) with a small lander of less than 400 kg (about 35 kg scientific payload) is investigated. The lander would be able to perform mineralogical, chemical/isotopic, and physical in-situ measurements as well as radio science experiments. A solar electric propulsion (SEP) system was selected for the baseline mission. The SEP system would enable the spacecraft to rendezvous 1996FG3 within 13 months. Later, a sample return mission to perform a study of the NEA material in Earth laboratories (e.g. for microstructure and isotope analysis to determine the age and the evolution of the body) would be the logical next step.
A solar sail would also be an option for this mission with the benefit of a reduced launch mass, allowing eventually a cheaper launcher. The transfer time for a near-term solar sailcraft (maximum thrust to mass ratio at Earth distance of 0.14 μN/kg), however, would be much longer (about 4 years) [22]. A solar sail offers also the opportunity for a relatively low-cost sample return [23,24].

LONGER-TERM STRATEGIES AND REQUIRED TECHNOLOGIES

The presented robotic exploration scenarios shall not be understood as alternatives in competition but rather as complementary and more or less parallel activities in the timeframe of the next 10 to 15 years. During that period the role of the Moon and NEAs as a useful platform and stepping stone for more ambitious missions including humans would have to be clarified.
Concerning the different techniques for landing – semi-hard and/or controlled soft – it appears that both have their specific application range, and should, therefore, be employed. Another very important exploration tool to be developed in Europe is a rover with onboard autonomy, artificial intelligence, and the capability to reach large distances. Also, ISRU technologies are not yet available on a suffi-

cient level [25]. Considering the long lunar night and the larger distance of Mars from the sun, efficient power technologies are required as well as novel propulsion systems for later human missions [26]. In addition, the ISS should be used to develop and demonstrate technologies related to long duration human presence in space like habitats and CLSS.

SUMMARY AND CONCLUSIONS

It has been argued that space exploration is a well defined interdisciplinary and application oriented self-contained research area, based on the interaction of the disciplines of space sciences, life and physical sciences in space, and human spaceflight. An approach for an integrated European space exploration strategy has been presented. The relevant destinations within the next decades were identified as the Moon, Mars and NEAs. From a scientific as well as an application point of view, all three destinations stimulate significant interest in the science community and the public, and promise new insights into our immediate neighborhood in space, which will eventually be explored and investigated by humans. Corresponding scenarios for robotic exploration missions within the next 10 to 15 years were outlined, taking also the recommendations of the European in-situ science community into account, which met recently at DLR Cologne. All scenarios should be considered, studied, and refined further to be implemented – more or less in parallel – within a future European exploration program, if possible in international cooperation. From a technological point of view, the Moon and NEAs are easier to reach. Whether they represent reasonable stepping stones to further destinations must be investigated in the exploration program to be established. The fact that they don't have an atmosphere makes them similar to most of the planetary bodies accessible to humans and particularly attractive for demonstrating landing technologies for future missions. Clearly, the most fascinating long-term goal for human exploration is Mars [27].

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