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Science and Exploration
using Space-Borne Platforms:

A REPORT ON SPACE SCIENCE IN SWITZERLAND

and recommendations for the future

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CaSSIS image MY35_006733_156. Crater in Mawrth Vallis, Mars. Credit: ESA/Roscosmos/CaSSIS

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MANAGEMENT SUMMARY

The Commission for Space Research (CSR) of the Swiss National Academy of Sciences (SCNAT) reviews and presents Swiss projects in the field of scientific space research every two years through a report to the international non-governmental organisation, COSPAR, (Committee on Space Research). The latest report was issued in 2018 and lists all recent and on-going Swiss contributions to hardware and/or software developments for instrumentation in scientific space research programmes. (This is distinct from purely scientific exploitation of data acquired in space). The CSR has summarized the current programmes herein.

Within this report, the CSR summarizes its position on future activities and on structural issues within the Swiss system with a view to improving the functioning of the system as a whole.

The CSR has identified projects that are of importance for the Swiss scientific instrumentation community in the period 2021–2024. Furthermore, because of the long lead-time in space research projects, the CSR has identified major projects scheduled for launch in the 2025–2035 timeframe that the Swiss community aims to participate in.

The CSR has also reviewed the processes and financial structures used to support instrument-related Swiss space research. It has agreed a series of recommendations that are designed to support a strong, scientifically excellent, instrument-related programme within an expanding world of opportunity.

The recommendations emphasize

- **continued support for the PRODEX programme and strong participation within the European Space Agency's scientific programmes as well as provision for opportunistic participation within the programmes of other agencies**
- **minimizing risk within instrument developments**
- **improved communication within the Swiss system (government, institutions, and industry)**
- **enhanced clarity in the funding mechanisms and procedures for instrument-related scientific space projects.**

The instrument-related space programmes proposed for the coming years by the Swiss groups are exciting and will allow the community to grow within the international space science community. A rough costing suggests that a small but significant budget increase to the PRODEX instrument would allow much of the programme proposed to be completed.

This report should be regularly revised and we recommend that this should be on a four-yearly cycle with the next update due to be completed no later than the end of the 1st quarter of 2023.

SUMMARY OF MAJOR FINDINGS

ENHANCING SWISS INTERESTS

1. The Swiss space science community recognizes that ESA is Switzerland's main instrument to implement space policy and continues to support ESA as its primary means of accessing space.
2. The Swiss Space Office should continue to ensure independence of Swiss institutes with respect to hardware provision and reject any efforts to reduce institutes to pure hardware providers.
3. The opportunities to participate in the programmes of agencies other than ESA are becoming increasingly important to the Swiss community. We recommend that a regular assessment of the relative contributions to the programmes of each agency be performed in consultation with the community.
4. A review of how the scientific exploitation of Swiss instrument developments can be secured as a means of guaranteeing return on the investment is required and appropriate actions taken.

NETWORKING AND INTERACTION

1. We understand that there are moves to make Federal Commission for Space Affairs (CFAS) recommendations more visible to the community at large. We would welcome and support an increase in visibility of CFAS recommendations.
2. An improved networking of Swiss infrastructure and space capabilities, such as the intended Swiss Institute for Planetary Sciences, should be promoted to give broader access to space-borne science in general.
3. Switzerland should ensure that its representatives on ESA's working groups, Space Science Advisory Committee and Science Programme Committee maintain close contact with each other to ensure that Swiss interests are correctly aired during the decision making process.
4. A review of the relationship between institutes developing space technologies and those performing scientific exploitation should be made to identify synergies and establish possible methods for knowledge transfer across scientific generation boundaries.

FINANCING

1. A significant increase in the level of resources for ESA's Science Programme appears to be fully justified and should be supported by Switzerland at the next Council of Ministers meeting.
2. The Swiss participation in ESA's PRODEX programme should be maintained and strengthened with additional resources.
3. The European Commission provides a valuable source of funding to the space science community. Ensuring the stability of this source of funding should be a priority for the future.
4. A specific line item in the budget should be opened to allow proper funding of the operational phases of missions.

ADDITIONAL RECOMMENDATIONS AND FINDINGS

1. Switzerland should continue to support an ESA operations budget line at the level of $\lesssim$10% of the science programme level of resources for mission extensions.
2. Definition of the requirements and tasks included in any PRODEX proposal should clearly show that risk has been sufficiently mitigated to limit the potential for cost overruns.
3. Evaluation of Swiss proposals to participate in the development of space instrumentation should ensure that all the capabilities necessary to execute hardware development commitments are present within the Swiss consortium.
4. The targeted distribution of funds from PRODEX between research institutes and industry is perceived as highly beneficial to both sides and should be maintained.
5. Records of the funding of smaller contracts via the institute funding contribution from PRODEX should be maintained by the institute.
6. European Commission funding of space instrumentation related projects is of significant interest to the Swiss scientific community and Switzerland should support expansion of this funding.
7. The communication between the Commission for Space Research and the Swiss Commission for Astronomy should be furthered to take advantage of all synergies within the Swiss astronomy community.
8. Proposals to the PRODEX programme must show that the capabilities to exploit the scientific results from the proposal are present in Switzerland. It is also necessary that the persons expected to exploit the scientific results are part of the initial proposal or that scientific exploitation is ensured over the long-term should a mission extend beyond a normal academic career.
9. The completion of the Swiss contributions to selected missions with instrumentation already committed is a necessary element of the programme and should receive high priority.
10. Switzerland should continue to play an active role in Mars research including active participation in any Mars sample return programme. The activities should also include consideration of participation in further remote sensing activities at Mars to provide global context.
11. In view of its novelty and pioneering research aspects, the appropriate structural actions should be taken to secure the long term support required for a Swiss participation to the LISA L3 mission hardware.
12. In assessing Missions of Opportunity and Small Mission proposals for support within the ESA framework, Switzerland should emphasize that projects should neither compete with ESA's existing programme, nor should they provide minor (e. g. low quality) addenda to Swiss communities that are already well served by existing programmes.
13. Given Switzerland's previous participation, an increase in the level of resources for ESA's biomedical research programme appears to be justified here and should be supported by Switzerland at the next Council of Ministers meeting.
14. While recognizing the diversity of requirements for operations and archiving across disciplines, the effort towards the establishment of a national center to support operations of space missions should be pursued.

FOREWORD

This roadmap for space science in Switzerland was produced by the Commission for Space Research (CSR) which is part of the Mathematics, Astronomy and Physics (MAP) platform of the Swiss Academy of Sciences (SCNAT). Following discussion within the CSR, and in consultation with representatives of the Swiss Space Office, it was decided to provide information and guidance on the interests of Swiss scientists in space-borne instrumentation in a formal document. Specifically, information on possible developments for the 2021–2024 timeframe with a look into the future beyond 2025 was thought to be valuable to set a framework for future decisions and to assess the community's wishes for future scientific direction.

A sub-set of the CSR was allocated responsibility for collecting information on the different fields of research. The document was collected together and edited before being distributed to the CSR and the institutes the members represent for review. The CSR has representatives from all institutes known to be involved in scientific space-faring activities. While we cannot exclude that small interests are held outside this community, the major institutions in the field have been consulted.

The scope of the document is defined in the first section. This is intended to ensure that the roadmap's place with respect to other communities (e.g. Earth observation and ground-based astronomy) is clear.

The authors have prepared a series of recommendations. They have also assessed their programme priorities with respect to the estimated PRODEX budget for the coming years to ensure that the scenario envisaged is approximately compatible with the available resources. It should be noted that the CSR is not responsible for making PRODEX proposals or allocating resources to programmes. However, we have used our judgement to produce estimates that appear realistic.

We hope that this first attempt at writing a roadmap for instrument-related space sciences is useful and that it can form the basis for future updates (e.g. on a four-yearly cycle) as a rolling support to decision-making at SBFI.

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TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

FIGURE 1 Principal Investigator Samuel Krucker of the Fachhochschule Nordwest Schweiz with the STIX experiment that is scheduled to fly on ESA's Solar Orbiter in 2020. The experiment is designed to provide high resolution images of the Sun at X-ray wavelengths. (Credit: Jan Hellman)

SCOPE

The Swiss Space Implementation Plan[1] within Education, Research and Innovation for 2018–2020 (SSIP) contains the following paragraph:

"The strength in designing, building and operating space-based instruments positions Switzerland among the leading nations at the global level of Space Science. Obviously such activities also present opportunities for long-term research networks in areas of strategic importance, yet it also increasingly requires improved coordination and prioritization within the community."

The present document describes the future interests of the Swiss scientific community in the development, operation, and exploitation of scientific instruments for space research and is in (partial) response to the text above. It is intended as a "roadmap" to guide policy makers in future decisions.

The timeframe for the "roadmap" is to provide an assessment of aims and goals for the 2021–2024 timeframe with a look into future goals covering 2025–2030. Hence, it is intended that this document will provide guidance for decision-making for the next 10-15 years. However, it should be apparent that the timescales to be considered range from short-term (1–2 year) projects for near-Earth orbit up to 30 years into the future when spacecraft missions taking 15–20 years (from planning to completion) are also taken into account. As a result, the planning activity is a complex one.

For the purposes of this document we consider the following subjects to be within scope

- In situ investigation of the Solar System (including planets, moons including Earth's Moon, small bodies, dust, and the interplanetary medium)
- Space-borne astronomical observatories (including observations of astronomical objects using radiation over the full electromagnetic spectrum, observations of gravitational waves, observations of particles from remote sources, and remote observations and in-situ of our own Sun)
- Space-borne measurements of physical properties and constants (e.g. tests of the equivalence principle) and phenomena requiring microgravity
- Studies of the Earth's properties and environment above 100 km altitude (including Earth's magnetosphere and material – both natural and man-made – within it).

For the purposes of this document we consider the following subjects to be OUT of scope

- Space-borne infrastructure that facilitates use of other scientific instrumentation (e.g. relay orbiters or the International Space Station itself)
- Space-borne observation of Earth where the observing goal is below 100 km altitude. It is expected that this would be addressed through the Swiss Commission on Remote Sensing (SCRS). We note, however, that some aspects of planetary geodesy straddle this divide
- Ground-based observations including support observations (e.g. ground-based follow-up). We note here that this topic and the ground-space astronomy relationship will be discussed in a roadmap currently being prepared by the Swiss Commission for Astronomy (SCFA).

The development of technologies for space-related activities is carried out at several institutes, organizations and industries. However, this document specifically addresses only application to instrument development for space research while noting that, for example, European Space Agency (ESA) funded engineering technology development is an important aspect in maintaining space-related capabilities in industry.

[1] www.sbfi.admin.ch/sbfi/fr/home/services/publications/base-de-donnees-des-publications/swiss-space-implementation-plan.html

THE PRESENT SPACE-RELATED SCIENTIFIC LANDSCAPE IN SWITZERLAND

The latest version of the Swiss report to the Commission for Space Research (COSPAR) has been published in July 2018. This document provides a comprehensive summary of Swiss space-related activities in the scientific domain and illustrates that Switzerland has broad interests within space-related observation but also specific areas of expertise. It also shows that space research in Switzerland takes many forms including basic science, more applied research, and technology development. In addition, infrastructure development in support of space research activities is performed. In the following paragraphs, we shall briefly describe some of the main areas. A summary diagram is provided as Figure 2.

Planetary sciences (including exoplanets) is one of Switzerland's strengths and a scientific area of significant collaboration between many of the major academic institutions in Switzerland. The study of exoplanets and planetary formation is based around the Uni Bern – Uni Geneva leadership of the National Center for Competence in Research called PlanetS (NCCR PlanetS). This leadership is supplemented by significant participation from Uni Zurich and ETH Zurich with some support from EPFL. Switzerland continues to maintain its international leadership in ground-based observation of exo-planets and proto-planetary discs while simultaneously augmenting this through the develop-

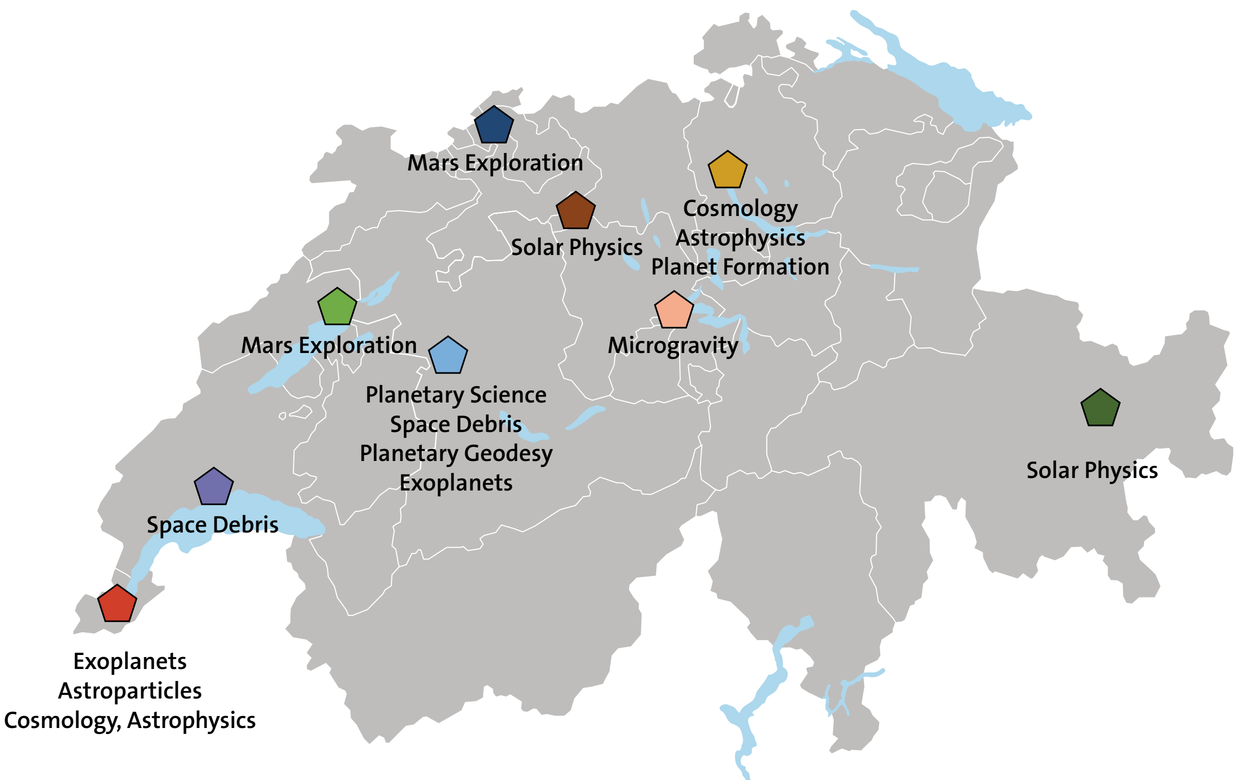

FIGURE 2 The centres in Switzerland that lead specific themes in space research. This diagram is geographical such that there is no separation between for example Uni Zurich and ETH Zurich. (Credit: Nicolas Thomas)

ment of hardware for space missions. The first Swiss scientific satellite, CHEOPS, will launch in 2019. This spacecraft will carry a 35 cm aperture telescope for observing exo-planet transits and will place Switzerland at the forefront of space-based studies of exo-planet properties. In this fast developing field, participation in other space programmes, such as PLATO, has already been actively sought to maintain the prominence of Switzerland in this field far into the next decade. The successful collaboration of the NCCR has also ensured coordination of space-related efforts with the ground-based programme. This is a key advantage of the current Swiss landscape that should be cemented through the foundation of a Swiss Institute for Planetary Science (SIPS) – an intended output from NCCR PlanetS foreseen for the 2022 – 2026 timeframe. SIPS is intended to coordinate both teaching and instrument development resources (both space and ground-based developments) within the field of planetary sciences in its widest sense. Although the planning for SIPS is at an early stage, this strategy may prove to be a model for collaboration in other space-related fields in Switzerland.

While the recent drive into exoplanet science has been very visible, the space-borne activities could only be envisaged because of the strength of Swiss hardware development for Solar System exploration. This remains a key area within the Swiss community with participation most recently in programmes to small bodies (specifically, comets), Mercury, Mars, and the Jovian system. While Uni Bern remains the dominant Swiss institute in this field, ETH Zurich and EPFL have also participated in space programmes (most notably ETHZ's contribution to the Mars seismometer on NASA's InSight) while Uni Zurich is now increasing its contribution to theoretical studies of planetary interiors. Uni Basel is also working with the Space Exploration Institute (Neuchatel) on the CLUPI imager for the ExoMars 2020 rover. Uni Basel previously developed the atomic force microscope for NASA's Phoenix lander. The field of planetary atmospheres is supported by the microwave spectroscopy group in Uni Bern which is contributing to the JUICE mission through the SWI instrument.

Planetary geodesy is a related field. The determination of Earth's static and time variable gravity field from multiple (including space-based) data sets has formed the basis for strong celestial mechanics groups at the University of Bern and at ETH Zurich. Missions such as the E-GRASP/Eratosthenes ("European Geodetic Reference Antenna in Space") provide scientifically important elements. The extension of this work to other planetary bodies to place constraints on their interior structure, rotation and tidal deformation has been proceeding using data from the GRAIL spacecraft and is expected to expand further through exploitation of data from the BepiColombo mission to Mercury. Current missions, in particular ESA's Trace Gas Orbiter (TGO), may allow the study of the CO_2 cycle on Mars and illustrates one of the possibilities for increased interaction between Swiss scientists in Solar System studies.

In heliophysics, the absence of a full professor in Switzerland covering this field (following retirements and re-direction) has necessitated changes in the structure. In 2019, the recently selected new director of PMOD/WRC in Davos is set to be appointed associate professor at ETH Zürich. With this arrangement, there will again be a professorship for solar physics with rights equivalent to a full professor and thus able to promote PhD theses. Switzerland has continued to support space-based solar physics through financing the STIX instrument for Solar Orbiter (due to launch in 2020) through the Fachhochschule Nordwest Schweiz, as well as hardware contributions from PMOD/WRC to two other Solar Orbiter experiments, namely EUI and

SPICE. PMOD/WRC has also built and flown radiation monitors on various spacecraft.

In the field of space climate, a collaboration over the past 10 years between PMOD/WRC, ETH Zürich, Uni Bern, and EAWG has extensively investigated the solar influence on the terrestrial climate in the framework of two successive SNF-SINERGIA projects. The main result, that a possible decrease of the solar activity could temporarily slow down the warming of the terrestrial atmosphere by reducing the increase by up to 0.5 C, has attracted considerable attention. Otherwise, activity in the field of solar-terrestrial physics has been reducing over the past decade and, although this remains a frequent topic for scientific workshops and teams at the International Space Sciences Institute (ISSI) in Bern, which retains an interest, there is little work being carried out outside this. On the other hand, study of the interaction of the solar wind with the local interstellar medium has been significant based on participation in the IBEX mission. Higher accuracy measurements of neutral atoms from the interstellar boundary have been suggested and on 1 June 2018, NASA selected the Interstellar Mapping and Acceleration Probe (IMAP) mission with an expected contribution from Uni Bern.

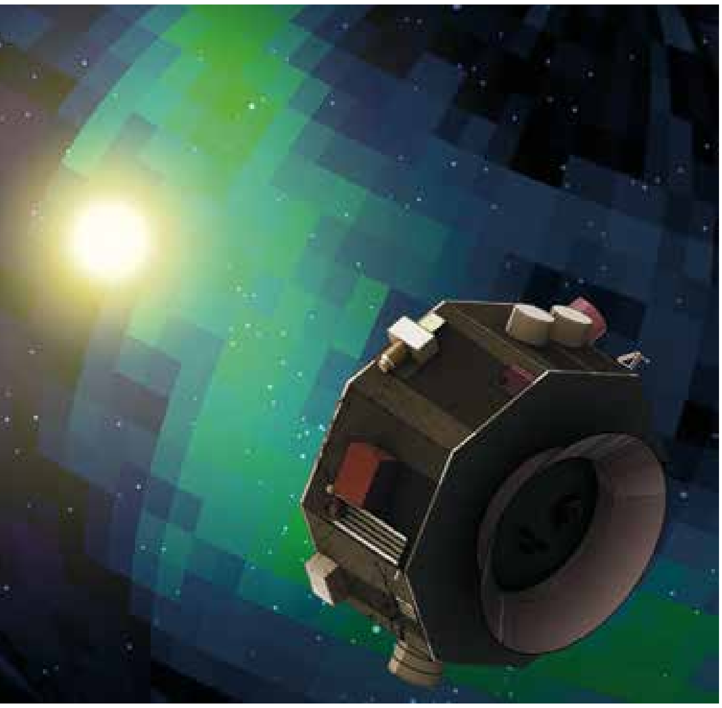

FIGURE 3 Artist's impression of the Interstellar Mapping and Acceleration Probe (IMAP) against a background indicating the flux of neutrals from the interstellar boundary. (Credit: NASA)

Access to space has opened new observation windows on the Universe because a large part of the electromagnetic spectrum (X-rays, gamma-rays, ultraviolet and a large part of the infrared radiation) and cosmic rays are blocked by the atmosphere. This has led to major advances in astrophysics. Other astrophysical domains have recently started to benefit from the advantages offered by space-borne observatories, in particular ultra-stable photometry and diffraction-limited optical imaging.

The Swiss community has taken advantage of the numerous possibilities. It is involved in the vast majority of ESA astrophysics missions, often with a very visible role. Most of the projects where Uni Geneva and FHNW are involved are in the domain of high-energy astrophysics (X-ray and gamma-ray observatories) and astroparticles. Contributions to cosmology (through ESA's Euclid mission, for example) are being made at EPFL, Uni Geneva, and Uni Zurich, whilst gravitational wave observations from space is a topic that enjoys broad support throughout the country centred around ETH Zurich and Uni Zurich. Uni Geneva is heavily involved in ESA's GAIA mission in the field of galactic astronomy. Numerical modelling work based on GAIA results is carried out at Uni Zurich. ETH Zurich is a partner of the European Medium InfraRed Instrument (MIRI) consortium for the James Webb Space Telescope (JWST) and contributes to the development of the hardware, the instrument calibration and the science exploitation of the Guaranteed Observing Time (GTO) that is awarded in return to the consortium. The hardware contribution was formerly led by the

Laboratory for Astrophysics at the Paul Scherrer Institute before the group was closed and the project transferred to ETH Zurich.

Switzerland now plays a frequent role in supporting ground-segment activities for astrophysics space missions. This has grown from the establishment of the INTEGRAL Science Data Centre at Uni Geneva. Geneva hosts one of the four Data Processing Centers for GAIA and is leading the ground-segment activities for the determination of photometric redshifts from Euclid data which is critical for understanding the nature of Dark Energy. In addition, Uni Geneva is leading the ground-segment activities, and in particular the operations, for the Uni Bern/ESA-led S-class mission CHEOPS. Smaller activities have also been developed for ESA's Planck cosmic microwave background probe, the Japanese mission Hitomi and the Chinese mission POLAR. Taken together, these indicate a broad range of activities in this field.

Space debris is becoming a topic of increasing concern to national agencies and it is clear that as the commercial market for low Earth orbit satellites booms the dangers are increasingly significant. As a space agency, ESA has a responsibility to ensure sustainability of its activities – including those connected to astronomy and space research. Much of this work falls outside the "classical" category of space research but development of instrumentation for space safety (in its broadest sense) is of interest. Uni Bern is providing support to ESA for collision avoidance and in-flight detector systems with some of this work funded through the European Community programmes. At EPFL, the development of low cost space debris collection systems is on-going with test flights being planned.

As in astronomy, ground-based observations are important to this field. Uni Bern is contributing to ESA's efforts to better understand the space debris environment through observation and modelling in the context of several ESA programmes. In particular it conducts the optical observation programme of the ESA Space Debris Office using the ESA 1m telescope in Tenerife and sensors of the Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald for the past 20 years. The identification of space debris sources and the safety of space operations in low Earth orbit rely upon this work.

Centers for microgravity research on living organisms are located in Lucerne as well as in the Zurich area. The Lucerne University of Applied Sciences and Arts maintains, in particular, a National Center for Biomedical Research in Space through the Space Biology Group.

Microgravity research in Switzerland is focussed mainly on bio-medical and biotechnological studies in the context of space medicine or mechano-biological dysfunction on Earth. Experiments are carried out under simulated or actual microgravity as well as under terrestrial conditions to address important questions concerning biological mechanisms of mechano-transduction.

Finally, we note that PSI hosts a proton irradiation facility (http://pif.web.psi.ch). This forms a useful scientific resource for the effects of radiation damage on flight hardware and the group has a strong Europe-wide reputation.

MAJOR SUCCESSES (2014 – 2018)

The Swiss community has registered several major successes in the past 4 years. Two high profile ESA Solar System missions (Rosetta and the ExoMars Trace Gas Orbiter) have been actively acquiring data in their primary science phases within this period and both carry major contributions from the Uni Bern. The ROSINA experiment (PI: H. Balsiger succeeded by K. Altwegg) on Rosetta is a suite of two mass spectrometers and a density sensor that was used to investigate the gas composition and density in the immediate vicinity of the nucleus of comet 67P/Churyumov-Gerasimenko from August 2014 through to September 2016. The suite has produced the most reliable and consistent measurements of gas density in the inner coma. The mass spectrometers have produced detailed measurements of the composition including detections of glycine – the most primitive amino acid.

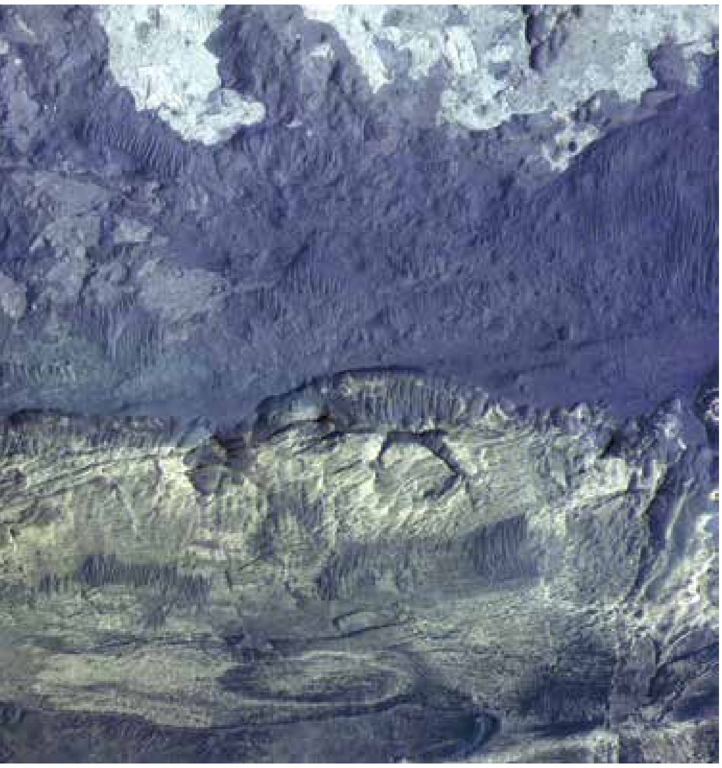

FIGURE 4 CaSSIS image of Ius Chasma showing variation in colour and texture at 5 metre resolution. (Credit: ESA/Roscosmos/CaSSIS)

The imaging system onboard the ExoMars Trace Gas Orbiter (CaSSIS) was built almost entirely in Switzerland. The spacecraft was launched in 2016 and entered its final orbit in April 2018. The CaSSIS imager has been returning imaging data at a rate of over 100 targets a week since mid-May 2018. CaSSIS is expected to provide new insights into the diurnal cycles of H_2O and CO_2 surface ice and continue the investigation of dynamic phenomena (e. g. gullies formation, dust motion, erosion and mass wasting) during its 2-year prime mission and hopefully beyond.

The preparation and delivery of the SEIS instrument for NASA's Discovery mission, InSight, was completed and the spacecraft launched in May 2018 before landing on the surface of Mars on 26 November 2018. SEIS contains electronics developed at ETH Zurich and is expected to provide the first assessment of the Martian deep interior through the study of "Marsquakes". The use of CaSSIS to identify impact sources of Marsquakes illustrates the potential for strong collaboration in this field.

The "Space Biology Group" of the Lucerne University of Applied Sciences and Arts has established the concept that the response of muscle cells to mechanical unloading is based substantially on an alteration of the intracellular calcium concentration that is controlled through modified gating properties of mechano-sensitive ion channels. For these studies, space-proven scientific instruments were introduced such as an electrophysiological setup for measuring transmembrane currents and a Digital Holographic Microscope for the optical analysis of the cellular calcium content. These two instruments were operated on sounding rockets as well as on planes performing parabolic flight manoeuvres.

A major recent success of the Swiss community in the domain of space-borne astronomical observatories has been the selection and development of CHEOPS, the first Swiss scientific satellite that will perform follow-up of exoplanet transits. Uni Bern has completed the integration of the instrument for CHEOPS. The instrument has been successfully delivered to the spacecraft and is expected to launch in the third quarter of 2019.

Similarly, the BepiColombo Laser Altimeter (BELA) was delivered to ESA by Uni Bern and launched on 20 October 2018 as part of the geodesy package to investigate Mercury. A smaller but important contribution to the SERENA particles package on the mission has also been provided by Switzerland through Uni Bern.

On the astrophysics side, over this period major advances have been obtained with the Gaia satellite. The second data release was the most cited result in astrophysics in 2018 and Gaia data are being used to generate more publications than HST at present. INTEGRAL data were used in the “multi-messenger” (gravitational waves and gamma-rays) detection of a kilo-nova and thus provided a first proof of the power of combining high energy astronomy with the new field of gravitational waves. In spite of a spacecraft failure a few weeks after launch, the first Swiss collaboration with the Japanese space agency JAXA on the Hitomi X-ray telescope, launched in 2016, led to important advances in the understanding of the most massive cosmological structures, galaxy clusters. Detectors were developed at Uni Geneva for the Chinese POLAR and DAMPE missions, both launched in 2016. POLAR studies the polarization of gamma-ray bursts while DAMPE tracks cosmic rays in an attempt to detect traces of Dark Matter. Finally, ETHZ led a major technological development for LISA Pathfinder, which prepares for a significant Swiss contribution to the future LISA gravitational-wave observatory.

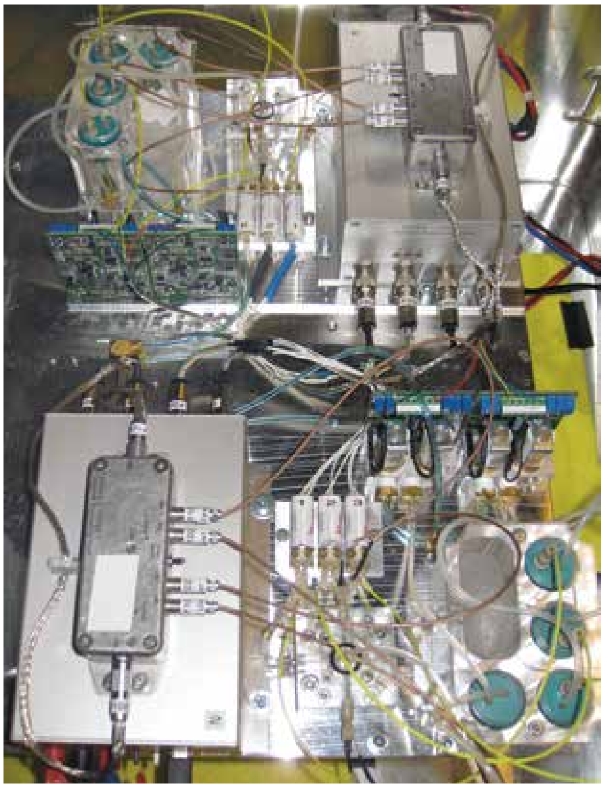

FIGURE 5 Electrophysiological setup to record transmembrane currents of living cells during weightlessness. (Credit: HSLU)

FIGURE 6 The BepiColombo spacecraft arriving in Kourou for launch in October 2018. The BELA and SERENA/STROFIO instruments were provided by Switzerland. Swiss industrial contributions (APCO Technologies) can be seen prominently in this particular photograph. (Credit: ESA)

FIGURE 7 The CHEOPS instrument in the clean room at the University of Bern. (Credit: Uni Bern)

In collaboration with RUAG Space (formerly HTS) a cryogenic mechanism was developed for the MIRI experiment on JWST and qualified for operations in space under cryogenic conditions. With Syderal SA, the instrument cryogenic cables were manufactured and optimised for minimal heat conduction. Both hardware contributions were funded by the Swiss Prodex programme. After the delivery of the hardware for system integration in 2008 the project was continuously supported by ETH Zurich: Engineering expertise was provided continuously and several staff members participated in the preparation and conduction of the test and calibration activities before and after MIRI was delivered for integration into JWST.

The European Gravity Service for Improved Emergency Management (EGSIEM, http://egsiem.eu) was the first H2020 project of Uni Bern (2015 – 2017). EGSIEM delivered the best time-variable gravity products for applications in Earth and environmental science research by unifying the knowledge of the entire European GRACE community. After the end of the project the established combination prototype service has been installed as COST-G (COmbination Service of Time-variable Gravity field solutions) as the new product center for time-variable gravity field models under the umbrella of the International Gravity Field Service (IGFS) of the International Association of Geodesy (IAG). COST-G shall become operational with the availability of data from the GRACE Follow-On mission successfully launched on 22 May 2018. Although this work is outside the scope of space research defined here, the tools and techniques used may be applicable for other Solar System objects (e. g. the Moon, Mars and Mercury).

The TEC directorate of ESA has its own series of technology development satellites called PROBA. PROBA-2 was launched in 2009 and is still operational with the PMOD/WRC provided the LYRA experiment (a EUV and UV radiation monitor). TEC intends to test formation flying with its PROBA-3 mission, which will use two spacecraft to produce a 150 m long coronograph system to observe the solar corona to unprecedented proximity to the Sun. This experiment has Swiss participation and, in addition, the occulting spacecraft will carry DARA, a solar irradiance radiometer experiment provided by PMOD/WRC. It is currently expected to launch in 2020.

SWITZERLAND'S PLACE WITHIN THE INTERNATIONAL SPACE-RELATED SCIENCE COMMUNITY

By comparison with the major space-faring nations, Switzerland is a small country. However, in the science domain, it punches well above its weight. It does so through its membership of the European Space Agency and through carefully considered bilateral collaborations that provide high visibility. It has also recently taken on leadership of a small scientific satellite, CHEOPS, and has the potential to maintain this successful record well into the next decade. In this section, we look at the international landscape within which Switzerland operates.

SWISS LEADERSHIP

CHEOPS, a small satellite to observe exoplanet transits, was a Uni Bern-led project with significant support (at the 50 MEuro level) from ESA. It formed the first S-class mission in the ESA Science Programme. The development of CHEOPS illustrated that Switzerland has the capability to develop and launch small satellites but it is to be noted that ESA is not considering future S-class missions in this form principally because Switzerland appears to be the only small country able to take leadership of such projects. The next mission designated as S2 is the collaboration with China on SMILE (see below).

The first Swiss-led satellite to be launched was a cubesat called SwissCube led by EPFL and was developed mostly by students with very limited science goals. Although SwissCube achieved many of its goals, it also demonstrated a fundamental issue with cubesats, namely that the science return is limited and very tight focus on highly specific goals is needed to fit within the resource requirements. It was also shown that support from the experienced laboratories was necessary to complete testing of the hardware because individual schools and institutes may not have the needed facilities.

It is apparent that Switzerland has the capability to take the lead on small missions up to a total cost of roughly 150 MEuro missions (although the CHEOPS experience shows that reaching the highest cost is financially and technically challenging requiring very accurate and careful planning). However, in all cases, while formal leadership might be from a Swiss organization with limited space experience, involvement of institutes and organizations with well-established knowledge of space instrumentation is required to ensure success and secure the investment.

– **RECOMMENDATION: Evaluation of Swiss proposals to participate in the development of space instrumentation should ensure that all the capabilities necessary to execute hardware development commitments are present within the Swiss consortium.**

The Swiss academic community, in general, has considerable experience and capability but this is distributed over many organizations. CHEOPS has illustrated that coordination of expertise can provide considerable benefit on a larger scale programmes while, at instrument level, similar benefits of strong inter-Swiss collaboration have been evident in the past (e. g. between Uni Bern and FHNW on CaSSIS). Increased contact and better networking would probably result in more efficient use of resources. But a more tangible benefit may result if new players can gain access to such a network thereby broadening the space research base.

– **RECOMMENDATION: An improved networking of Swiss infrastructure and space capabilities, such as the intended Swiss Institute for Planetary Sciences, should be promoted to give broader access to space-borne science in general.**

PARTICIPATION WITHIN ESA

Switzerland was a founding member of ESA and contributes to the mandatory science programme and to optional programmes including some of interest to the Swiss science community. As indicated in the Swiss Space Implementation Plan within Education, Research and Innovation for 2018–2020, ESA remains Switzerland's main instrument to implement space policy. The Swiss science community recognizes this and continues to support ESA as its primary means of accessing space.

– RECOMMENDATION: The Swiss science community recognizes that ESA is Switzerland's main instrument to implement space policy and continues to support ESA as its primary means of accessing space.

THE MANDATORY SCIENCE PROGRAMME

A draft of the programme to be proposed by ESA's Director of Science to the Council of Ministers conference in 2019 is summarized by the waterfall diagram in Figure 8. This diagram shows (in light blue) the ESA missions that are already adopted. It should be assumed that the large (L) missions, Athena and LISA, and the M mission, Ariel, will be adopted in due time.

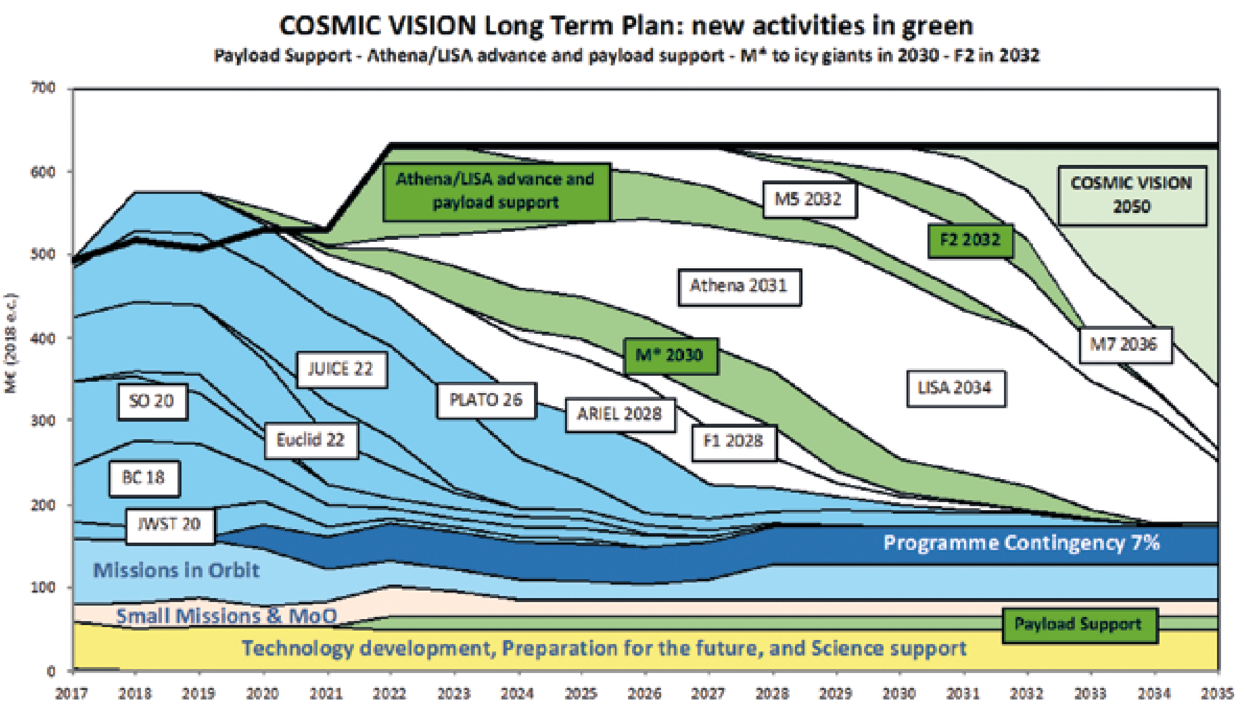

FIGURE 8 Waterfall diagram of the draft proposal by ESA's Director of Science for the Council of Ministers conference in 2019. (Credit: ESA)

Figure 8 illustrates several fundamental points about Switzerland's participation in ESA's Science Programme. First, Switzerland is only a participant in the programme definition – ultimately the ESA partners decide the programme so that, while Switzerland has influence and participates in the decision making process, it is not controlling the mission selection. Secondly, the programme is (mostly) fixed for much of the next decade and hence Swiss activities within the ESA science programme can be planned (albeit with a little uncertainty). Third, at ESA there is a budget line available for the operation of missions in orbit beyond their prime mission – so-called mission extensions. This is capped at roughly 10% of the total science programme. In general, the scientific community (including the Swiss community) strongly supports mission extensions because the scientific return is relatively high for a fairly low cost. Existing teams can also be maintained. However, the cost cap is necessary because continued operation of old spacecraft can reduce the resources available to develop new missions. Critical assessment is therefore necessary, taking into account the capacity of communities to service multiple missions in parallel and ensuring that ESA maintains a broad programme.

– **RECOMMENDATION: Switzerland should continue to support an ESA operations budget line at the level of $\lesssim$10% of the science programme level of resources for mission extensions.**

The budget also includes a line for small missions and missions of opportunity (MoO). These are (typically) contributions from the Science Programme to support a specific aspect of a mission or payload element of a member state or an external partner (e.g. the Chinese Academy of Sciences). This programme element is a relatively small component of the entire programme but it fulfils a very useful function. ESA's Science Programme is broad but it cannot include all areas of scientific interest at any one time. MoO's are a means of maintaining European (and Swiss) participation in space-based activities by buying into missions from other agencies. The difficulty in selecting these MoO's for funding is that opportunities present themselves irregularly, there is little or no competition in the recommendation process, and there is an element of "first-come, first-served". Furthermore, active science attracts and hence already strong research areas receive external requests for support leading to further concentration of resource allocation and against the "spirit" of the budget line.

– **RECOMMENDATION: In assessing Missions of Opportunity and Small Mission proposals for support within the ESA framework, Switzerland should emphasize that projects should neither compete with ESA's existing programme, nor should they provide minor (e.g. low quality) addenda to Swiss communities that are already well served by existing programmes.**

The Science Programme Committee (SPC) is the decision-making body for ESA's Science Programme. It is to be noted however that the ESA Executive and SPC are advised scientifically by the Space Science Advisory Committee (SSAC) which is itself advised by working groups (SSEWG for Solar System and AWG for astronomy). It is usual that the scientific recommendations of the SSAC are followed by SPC in deciding the future programme, approving mission extensions, and reviewing proposed missions of opportunity. Although appointment to these committees is ad personam, the membership is selected according to political as well as scientific balance. Other member states do take advantage of this. While political interference with the scientific (bottom-up) process should be minimized, information flow is important in establishing responses towards proposals from the Executive.

– **RECOMMENDATION: Switzerland should ensure that its representatives on ESA's working groups, Space Science Advisory Committee and Science Programme Committee maintain close contact with each other to ensure that Swiss interests are correctly aired during the decision making process.**

Finally, the current draft proposal is requesting a 20% increase in the level of resources from 2021 onwards. This is a substantial increase but such an increase appears to be fully justified based on the erosion of purchasing power and the significant increase in GDP of the Member States relative to the science programme level of resources. The new programme elements proposed to use such an increase are scientifically exciting while ensuring the programme remains robust.

– **RECOMMENDATION: A significant increase in the level of resources for ESA's Science Programme appears to be fully justified and should be supported by Switzerland at the next Council of Ministers meeting.**

ESA has proposed to use this increase for specific purposes (marked in green in Figure 8). As these items are yet to be decided, we shall discuss them further in relevant scientific sections below.

SPACE SCIENCE WITHIN THE OPTIONAL PROGRAMMES

Several of ESA's directorates have offered optional programmes connected to space sciences.

The Human and Robotic Exploration directorate (HRE) manages the ExoMars programme which Switzerland strongly supports. Instrument contributions to ExoMars include the Colour and Stereo Surface Imaging System (CaSSIS) for the Trace Gas Orbiter launched in 2016 and the Close-Up Imager (CLUPI) which is being prepared for the ExoMars rover to be launched in 2020. The Science directorate supports the science operations of the Trace Gas Orbiter through the MoO element of its programme. Mars Sample Return remains a goal of both NASA and ESA (recently the iMars 2 study investigated this further and announcements on collaborations between NASA and ESA have been made) but it remains to be seen how much of a financial commitment will be made to this programme in the immediate future.

HRE's programme also includes provision of ESA contributions to the Russian-led Luna-Resource Lander (Luna 27) mission which is aimed at exploring for the first time the South polar region of the Moon and measuring the water believed to exist there and determine its origin. The University of Bern is participating in Luna 27 with the neutral gas mass spectrometer (NGMS). This forms ESA's first steps in the development of a lunar exploration user community although at the present time there are relatively few scientists in Switzerland actively engaged in this field. Finally, the MAP (Microgravity Application programme) is also within HRE's remit and forms part of its SciSpacE (Science in Space Environment) programme.

The Technical directorate (TEC) supports some programmes that are of significant interest to Swiss space scientists. The EcoDesign for Space, technologies for space debris mitigation (SDM) and active debris removal (ADR) elements are of interest to the space debris community and it is to be expected that this programme will continue to be funded past the next ministerial conference. The relationship of its CleanSat programme to ambitions at EPFL (CleanSpace One) should be clarified.

TEC has also been involved in developing the Proba series of spacecraft for testing new technologies. Proba 3, for example, will be the first test by ESA of formation flying allowing studies of the solar corona and measuring the Total Solar Irradiance. Recently, TEC has been involved in studying the Asteroid Impact Mission (AIM) which would be Europe's contribution to the larger Asteroid Impact & Deflection Assessment mission (AIDA) run jointly with NASA. The NASA-led part of AIDA called the Double Asteroid Redirection Test, or DART, will approach the moon of asteroid Didymos, then crash straight into it at about 6 km/s. Following the ministerial conference of 2016, the ESA contribution has been renamed Hera, and is now foreseen to arrive some time after DART to determine the effect of the impact on the moon. While these missions are mainly technology-driven, the use of novel instrumentation is also encouraged. Hence, TEC also offers opportunities for scientific activity.

The directorate of operations is home for ESA's space situation awareness (SSA) program (to become the Space Safety Programme). The SSA programme consist of three segments, the Space Surveillance and Tracking (SST), the Space Weather (SWE), and the Near Earth Objects (NEO) segments. Switzerland takes part in the programme and has stakes in all three segments.

In the context of the SSA SST Segment, an ESA Expert Centre for passive optical and active laser observations is currently deployed at Uni Bern's Swiss Optical Ground Station and Geodynamics Observatory. This unique centre of excellence will profit from the recent substantial extension of the observatory (2 new domes and 3 new telescopes) and constitutes a major contribution of Switzerland to the ESA Space Safety Programme.

Within this program, ESA is planning to fly an optical instrument for the detection of small size space debris. Uni Bern is developing the software for the on-board and on-ground processing of the image data and will be partner for the optical payload hardware.

In the context of the SWE segment, ESA is planning to fly a space weather mission to the L5 Lagrange point, in order to monitor the solar activity aimed at Earth. PMOD/WRC will be hardware partner for an EUV solar imager instrument on that mission.

PARTICIPATION IN PROGRAMMES OF OTHER AGENCIES (INCLUDING NASA)

Purely from a financial perspective, ESA cannot cover the full spectrum of missions that European scientists would like to fly. Furthermore, the capabilities of ESA may not be at a sufficiently advanced level to allow missions to some targets. Outer solar system missions, for example, require nuclear power sources which Europe is not yet in a position to offer. It is also frequently the case that other agencies or proposers to other agencies invite Swiss groups to participate in their programmes because of their specific capabilities and/or expertise. Finally, missions developed by other agencies may overlap existing expertise in Switzerland and it becomes almost mandatory to participate to maintain a Swiss leadership position in the field.

The interests and needs of the community dictate that participation within the programmes of other agencies should be possible if it can be justified and financially supported. One should note, however, that Switzerland has no control over these programmes (through a programme board for example) and hence, continuous, stable, development of any programme with these agencies on the longer term cannot be guaranteed. Furthermore, if PRODEX is used for funding these participations, approval by ESA's Science Programme Committee is also required.

NASA

As the largest space agency in the world, NASA has a large palette of missions and programmes in which Swiss scientists may participate. The three main programmes in solar system research are Flagships (e.g. Europa Clipper), New Frontiers (e.g. OSIRIS-Rex), and Discovery (e.g. InSight). Within solar physics, the Solar Terrestrial Probes (STP) programme has included missions such as the Solar Terrestrial Relations Observatory (STEREO) which carries Swiss hardware as part of the PLASTIC experiment and RHESSI, a Small Explorer, with a significant hardware contribution from PSI. In the astrophysics area, NASA is currently building the James Webb Space Telescope that will carry European instruments managed through ESA while other missions such as TESS have scientific collaboration with Switzerland through agreements with the CHEOPS consortium. Another mission of interest here might be the infrared survey telescope, WFIRST, although its future is currently uncertain.

The above indicates that there are, in general, many possibilities to participate in some way in the NASA programme. Hardware contributions are also accepted, if the technology is suitable, as a means to reduce US costs of a mission/instrument proposal within the highly competitive NASA system. Given the higher frequency of missions, this also allows continuity in research areas if one can participate. On the other hand, the competition for new missions is fierce with, for example, 25-30 proposals being sent in to NASA for 2 slots in the Discovery programme. Hence, even if multiple contributions from Switzerland are proposed, the chances of successful selection are <10% and there is very little chance of more than one contribution being implemented. However, the rewards for success are often high because the selected missions are high profile and usually of high scientific value. This suggests that Switzerland must seek to participate in these programmes to maintain its position in cutting edge science.

JAXA

Japan is one of the leading countries in space science having initiated their space activities nearly 50 years ago. The country has rich history in X-ray and infrared astrophysics and Solar system exploration (e.g. Hayabusa). Collaborations between Swiss investigators (Uni Bern) and JAXA were started with SARA instrument for the Indian spacecraft, Chandrayaan-1. A major involvement in the Hitomi

X-ray satellite was the instrumentation developed by Uni Geneva. While the mission ended after only a few weeks, the compelling scientific return has led Switzerland to participate in the recovery mission XRISM. Further joint ventures have included work on the BepiColombo Mercury Magnetospheric Orbiter and the laser altimeter, GALA, foreseen to fly on ESA's JUICE mission to Ganymede. It appears that Japan would like to increase its cooperation with ESA and will become a significant partner for Athena. This would be significantly increased should SPICA be selected as M5.

ISRO AND CNSA

The newer space nations, India and China, are becoming increasingly active in the field of science in space. The ISRO mission, Chandrayaan-1 (with participation from Uni Bern), and the CNSA Chang'e programme demonstrate the independent capability of these agencies and collaborative missions with ESA and other international partners are now occurring regularly. There are both scientific and political reasons for participation in the programmes of these agencies. Collaborations with China started at Uni Geneva with the DAMPE and POLAR missions but several institutes have established plans to collaborate with China for range of missions, from the Sun to the Solar system, to astrophysics, the two main projects being HERD and eXTP.

ROSCOSMOS

The Russian space agency, Roscosmos, supports experiments on the Space Station and is intending to launch Luna-Glob (Luna-25) in 2021, Luna-Resurs (Luna-27) in 2023, Luna-Grunt (a lunar orbiter with penetrators) in 2025 and Venera-D (a Venus lander) also in 2025. It is also making a significant contribution to the ExoMars rover programme.

Luna-Resurs now has instrumentation from Switzerland and ESA is also now involved in the mission. The intention is to go to the south polar Aitken Basin region. As far as we are aware, the only astronomy mission discussed within the Russian system is Spektr-UV, also known as World Space Observatory-Ultraviolet (WSO-UV). It is a proposed space telescope intended for work in the 110 nm to 320 nm wavelength range. This mission has been proposed in various forms for nearly two decades.

OTHER AGENCIES

At the present time, some national agencies (e.g. CNES) occasionally launch scientific satellites. It cannot be ruled out that in the mid-term, opportunities to participate in a programme from another agency might arise. However, these opportunities will be rare. This might change quickly, however, if commercial flights start to offer scientific payload slots and careful attention should be paid to any development in this direction.

– **RECOMMENDATION: The opportunities to participate in the programmes of agencies other than ESA are becoming increasingly important to the Swiss community. We recommend that a regular assessment of the relative contributions to the programmes of each agency be performed in consultation with the community.**

RELATIONSHIP OF SWISS SPACE PROGRAMMES TO OTHER ORGANIZATIONS

SPACE BIOLOGY

Swiss researchers pioneered the work in cultivating biological cells in space. They were the first ever who operated an incubator specialized for cultivating human white blood cells in low orbit. This Swiss incubator used for that has laid the ground for similar instruments built and applied by NASA afterwards. Since that founding experiment, which was on board the Space Shuttle “Columbia” 1983, more than 30 research projects from Switzerland have been conducted under this topic in crewed space laboratories (International Space Station, Russian “Mir” Station etc.) as well as on automated satellites and on sounding rockets flying under European (ESA), Russian (Roskosmos) and U.S. flags (NASA, Space-X). Most of the hardware used for the execution of the mentioned experiments were financed through the “PRODEX”-programme. The focus of research topics that Swiss researchers are exploring, has widened in the meantime substantially. Nowadays, not only the behavior of human immune cells stands in the center of attraction but also muscle and bone cells as well as chondrocytes. All these cells belong to mechanosensitive tissues that show a high sensitivity to physical forces. The general questions the scientist want to answer is thus how biological systems respond to the influence of physical forces, either added or removed by microgravity.

Low gravity conditions achieved in space capsules offers an exceptional environment in which biological cells exhibit fascinating behavior. This has been attracting numerous scientists, from Switzerland but also from all over the world. Altered cell- but also tissue- and even organ-functions under microgravity condition open up new research fields that influence terrestrial biology and medicine significantly. Therefore, several Swiss research groups have dedicated their investigations to human physiology under weightlessness. Quite often, new or alternative treatments of patients on Earth are based on insights gathered by space experiments. It is likely, that in the future biotechnological processed conducted in space as well can be exploited more intensively for designing new pharmacological products for instance.

There is a strong commitment from all the major space agencies as well as private companies to increase the human space flight activities in the upcoming years. A crewed spaceship in the vicinity of the Moon called “Deep Space Gateway” is planned to replace the International Space Station. Furthermore, a “Lunar Village” shall be erected and NASA still wants to bring the first humans to Mars in the upcoming years. Before project like these can be realized however, major biomedical concerns need to be addressed otherwise the human space programme in general is in jeopardy. Therefore, substantial efforts in biomedical research are necessary.

– **RECOMMENDATION: Given Switzerland’s previous participation, an increase in the level of resources for ESA’s biomedical research programme appears to be justified here and should be supported by Switzerland at the next Council of Ministers meeting.**

GROUND-BASED ASTRONOMY

The Swiss Commission for Astronomy (SCFA) advises on policy in the field of astronomy and reflects on both ground-based astronomy and space-based astronomy. It serves a valuable function in coordination of ground-based and space-borne observations. In discussing the space element here, we have sought to be consistent with the SCFA’s roadmap for astronomy and have invited SCFA to review this document.

EARTH OBSERVATION

The Swiss Commission on Remote Sensing (SCRS) represents Swiss institutions that are involved in remote sensing and photogrammetry, as well as related thematic domains. The commission aims at fostering technology, research and product generation among its members by enabling a transdisciplinary and inter-institutional dialogue. While Earth remote sensing is outside the scope of this document, SCRS, as part of its remit, collaborates with the relevant actors of the remote sensing products chain, including all aspects ranging from technology and instrument development to data products generation and integration. Hence, there are some common interests between SCRS and the Swiss Commission for Space Research although contacts between the commissions could be strengthened.

FEDERAL COMMISSION FOR SPACE AFFAIRS (CFAS)

The Swiss space policy is decided by the Federal Council on the basis of recommendations made by the Federal Commission for Space Affairs (CFAS). Efficient coordination is required to ensure cooperation between the various federal agencies involved in the design and implementation of the Swiss space policy. This is the role of the Interdepartmental Coordination Committee for Space Affairs (IKAR), which acts under a mandate from the Federal Council.

– **RECOMMENDATION: We understand that there are moves to make Federal Commission for Space Affairs (CFAS) recommendations more visible to the community at large. We would welcome and support an increase in visibility of CFAS recommendations.**

We could also envisage a stronger interaction where, for example, the President of CSR is invited to CFAS meetings to improve communication.

RELATIONSHIP TO INDUSTRY AND OTHER ACTORS

ESTABLISHED INDUSTRIES

The companies in the SSIG (Swiss Space Industries Group) of SwissMEM [2] offer a widely varied and competitive range of solutions for use in the space technology sector: structural components, electronic equipment, sensors, software, optical and mechatronic equipment, and instruments. SSIG includes companies that are significantly involved in the wide-ranging, competitive Swiss space technology environment. These manufacturers and engineering companies play a prominent role in the broadly faceted, competitive Swiss space industry, and develop solutions for all areas of space business, including: structures for rockets, satellites, space transporters, and components for propulsion engines and scientific instruments. These companies participate in work on ESA's ongoing programmes, Arianespace and the International Space Station. Many of these companies actively participate in the development of flight hardware for the space science missions. They have also gained themselves a high place in the fiercely competitive European market by delivering quality, expertise, flexibility and on-time reliability. Space research is a driving force of innovation. Space engineering brings together virtually all the strategic technologies. The sector therefore stands out as a future-oriented, innovative and attractive employer.

The industrial landscape can benefit strongly from the interaction with academically-led space instrument development. The balance within the PRODEX programme between Swiss institute funding and Swiss industry funding remains an important pillar of the Swiss funding system. The relative distribution of work and financing between institutes and industry, taking into account the interests and competences of institutes and industry, is difficult to set with a well-defined formula. But consideration needs to be given towards achieving a fair distribution of work within a prescribed range of the percentage financial share and the content share.

It remains important that instrument leadership is hosted at an academic institution as the only means to guarantee scientific return on an investment. Hence, industry needs to respond to the desires of academia. Industries ranging from the large established players in space technology all the way to small- and medium-sized companies (SMEs) will be able to contribute and benefit from the institute-industry collaboration. However, the institutes must also acknowledge the competence of local industry and seek knowledgeable industrial partnerships at an early phase of any development. The competence of both institutes and their partner industries to complete an instrument development is a necessary pre-condition when judging Swiss internal priorities and should be a criterion for funding approval.

SWISS RESEARCH AND TECHNOLOGY ORGANIZATIONS (RTOS) AND THE ESA BUSINESS INCUBATION CENTRE SWITZERLAND

The transfer of technologies from the space instrumentation sector to industry for market exploitation is more challenging than it might appear to the casual observer. The specific needs of spaceflight (radiation tolerance, extreme temperature environments, robustness, etc.) are not necessarily appropriate for commercialization although miniaturization remains an important aspect. However, RTOs and the newly formed ESA BIC Switzerland [3] are available to support this task.

CSEM defines itself as a national innovation accelerator and is intended as a catalyst for the transfer of technologies and know-how from fundamental research to industry. Other research and technology organizations (RTOs) such as EMPA perform different roles but are also similar in that

[2] www.swissmem.ch/de/organisation-mitglieder/fachgruppen/raumfahrttechnik.html
[3] www.esabic.ch

they sit in the interface between academia and industry.

The establishment of an ESA Business Incubation Centre (BIC) in Switzerland was one of the measures recommended in the initial version of the Swiss Space Implementation Plan within Education, Research and Innovation for 2018–2020 (SSIP). ESA BIC Switzerland opened in November 2016 and is managed by ETH Zurich, in collaboration with IFJ, Impact Hub Zurich and AP Swiss. It is the place for start-ups with a link to space technologies in order to realize their innovative ideas. Thereby the innovation can either be a technology from space to be transferred to other areas of the economy on Earth or to adapt terrestrial technologies to new applications in space. Together with an extensive partner network consisting of a broad range of notable companies and renowned academic institutions, the BIC supports selected entrepreneurs with comprehensive commercial and technical support to help them kick-start their businesses. The space connection applies to multiple application fields such as navigation and positioning, communication techniques, Earth observation, materials, processes, signals or robotics. Thus far, the Swiss BIC boasts a portfolio of 19 start-ups from all over Switzerland, with technologies ranging from space solar panels for use on Earth to four-legged robots for exploration of other planets.

There are two selection rounds per year and applications are welcome all year round. Eligible to apply are all start-ups that are younger than 5 years, that are registered in Switzerland and which have the above mentioned "space connection". Every year up to 10 new start-ups can be incubated.

Across Europe, there are 18 further Business Incubation Centres and more than 580 start-up companies have received support to date.

The initiation of start-ups is becoming increasingly important within the Swiss landscape and the space instrumentation sector does need to be aware of the need for technology transfer and the possible role of start-ups. However, the challenge of transferring developments made in pursuit of scientific goals is significant and caution should be exercised in viewing this as a criterion for support.

SCIENTIFIC, INDUSTRIAL AND ECONOMIC IMPORTANCE OF THE INSTITUTIONAL SPACE SECTOR

The world space industry is a strategically important growth sector of high value-creating potential and great economic importance. While the commercial sector is becoming stronger and private initiatives are creating increasing impact, truly scientific endeavours are still firmly in the hands of large institutions such as the European Space Agency (ESA). For Europe to compete globally and to secure a leading position, the available resources must be efficiently deployed and activities pooled – tasks which are handled by ESA.

ESA coordinates and promotes the development of European space technology and ensures that the investment made goes to the lasting benefit of all Europeans. The EU aims to utilise the benefits of its space policy in its security, environment, transport, economic and social policy. ESA has an annual budget of about three billion euros. Switzerland contributes around 170 million francs annually. As a result, funds flow into research and enable Swiss scientists to participate in significant ESA missions, while the manufacturers benefit as suppliers to the research sector or directly through contracts awarded by ESA.

SWISS COLLABORATION

While the Swiss space market cannot match the biggest European countries for size, it can definitely keep up with them in terms of quality and innovation. For instance, the Ariane and Vega launchers, Galileo, MetOp or Electra, the exoplanet follow-up mission CHEOPS or the Sentinel satellites for Copernicus, Europe's Global Monitoring for Environment and Security system, are just some examples of important space programmes in which Swiss manufacturers have played a major role. There is hardly a current European mission which does not incorporate Swiss technology. None of this would be possible without Switzerland's early commitment to ESA, right from day one. ESA's ambitious programmes enable Swiss space companies to acquire the expertise that underpins its excellent reputation and promising position in the global growth market for space technology. Strengthening and further expanding this position has to be the goal in the coming years. This means not only overcoming technological and economic challenges but also dealing with difficult political issues. The leading players – science, politics and industry – have to work seamlessly together.

JOBS AND TRAINING

The Swiss Space companies in SSIG currently engage ~900 employees in the Space sector, but thousands of other professionals are also indirectly connected. Many of them are university graduates who find attractive jobs in the diverse areas of the production of space components and systems and contribute specialist expertise to the companies concerned. The employees of those companies concerned, not only come from a broad spectrum of educational and training backgrounds, but also represent a wide range of disciplines and therefore help to create a highly diverse store of expertise. This includes specialist knowledge in the fields of electronics, optics, precision mechanics, aero and thermodynamics, tribology, information technology, material science and additive manufacturing. This broad spectrum of expert knowledge enables the companies to provide innovative solutions to the complex challenges arising in the space sector.

The major point here is that we have active industrial partners and the group is strong and willing to participate. In addition there are companies providing contributions although their space related activities are a minor fraction of their business.

THE PRESENT FINANCIAL BOUNDARY CONDITIONS

The present structure of funding for instrument development programmes in Switzerland is characterized by fairly clear divisions (Figure 9). The institutions participate in discussions designed to result in a mission suggestion. A limited amount of travel money for this purpose is available through SCNAT but in general most of the load is carried by the institutions. Instrument concept development is sometimes funded by ESA out of its general studies programme – especially when the instrument in question may have a high degree of novelty and consequently at a low technical readiness level. The European Commission through its H2020 programme has been becoming an increasingly interesting possibility for this phase. Some laboratory studies might be needed at this point. The Swiss National Science Foundation (SNSF) can be a source or ESA may again provide contracts if the goal is clear enough. The main instrument development and build, however, falls under the PRODEX programme. This is where the most money is usually spent and only occurs after successful selection and transition into Phase B following an initial study phase (Phase A). Following instrument build, the data are acquired, calibrated, post-processed, and archived. The responsibility for funding the activities in this phase (Phase E) is currently a controversial issue in Switzerland and we shall return to this later. Finally, the scientific analysis phase is usually funded through the SNSF although there are occasionally some possibilities for additional funding through the European Commission's various programmes.

PRODEX

The Swiss space science capabilities began to develop even prior to the GEOS (Geostationary Earth Orbit Satellite) experience. In 1983, the Swiss space science community had participated in more than 38 different projects. The stakeholders came from five universities, two Federal Institutes of Technology and three additional institutions. Despite this quite significant number, only few of these projects included the development or manufacturing of the required scientific hardware. The reason for this lay in the continuing difficulty of obtaining funding for such an activity.

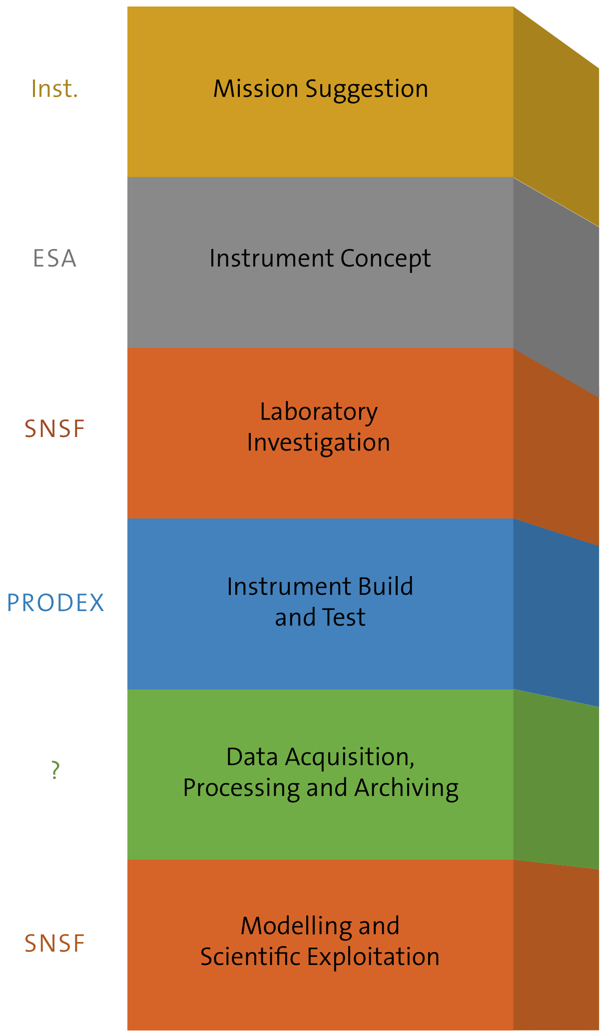

FIGURE 9 The 6 main elements of an instrument development programme with the funding responsible indicated on the left. This is an idealised picture but represents the type of approach normally discussed at the start of a project. (Credit: Nicolas Thomas)

The breakthrough came in 1986 with the implementation of PRODEX within the ESA framework. A brainchild of the Swiss Delegation to ESA, PRODEX became a success, not only for Switzerland but also for ESA and its Member States. Specifically, the smaller Member States saw the opportunities provided by such a programme and today ESA-PRODEX counts 15 Participant States out of its 22 members.

In Switzerland, the effects of PRODEX were felt almost immediately. For the first time, science teams were no longer limited to the exploitation of data but could propose or at least contribute to experiments by developing scientific hardware for space-based missions. More and more groups and institutions from across the spectrum of space activities – from astrophysics and the study of the solar system, to microgravity and Earth observation – became involved. The most recent flagships of PRODEX are the CaSSIS and ROSINA hardware at Uni Bern, the STIX instrument at FHNW, the CLARA/DARA instruments of PMOD/WRC, and the Gaia and Euclid science ground segment developments at Uni Geneva. Numerous other developments throughout Switzerland enable the Swiss science community to propose and even orient the European and international space science by providing the combined competence of Swiss R&D shared between Universities, research institutions and last but not least industry.

In terms of financial development and budgets the Swiss investment in PRODEX has continuously increased. Organised by five-year periods, the annual share of Switzerland increased from roughly 8 Mio CHF in the late 1990's to around 18 Mio CHF in the current period. To confirm and foster the quality and success of the Swiss Space Science community, the Swiss Space Office advocates for a comparable modest increase to 20 Mio CHF per year for future periods. This will also compensate for the loss of purchase power over the last decade.

We note that the proposed increase in ESA's Science Programme allowing new missions, almost certainly needs to be matched by increases in national budgets to support the required additional instrumentation. In addition, if we wish to further exploit the opportunities within NASA's programmes and the programmes of other agencies and thus maintain and indeed enhance a strong, competitive, scientific community, additional funding for the PRODEX programme appears to be necessary.

The PRODEX scheme as implemented in Switzerland envisages a long-term average of a 50:50 distribution of funds between Universities/Research Institutes and industry as a way of encouraging both to produce the highest quality instrumentation together. This can be achieved either through using industry as a "prime" for an instrument or part thereof or through using multiple smaller industries to provide elements where the coordination and management is provided by the institute. Both approaches have their place in instrument development but, in assessing the approach to be adopted, the competences of all sides need to be matched to the challenge.

Concern has been expressed in the past about cost control in scientific instrument development. Financial risk often results from insufficient definition at the time of contract signature (either with institutes or with industry). On the other hand, in completely novel instrumentation development, there is often uncertainty and risk-free development is illusory. However, proposals for risk mitigation and the extent of residual risk should be transparent from an early stage to support control of cost.

– **RECOMMENDATION: The Swiss participation in ESA's PRODEX programme should be maintained and strengthened with additional resources.**

– **RECOMMENDATION: The targeted distribution of funds from PRODEX between research institutes and industry in Switzerland is perceived as highly beneficial to both sides and should be maintained.**

– **RECOMMENDATION: Definition of the requirements and tasks included in any PRODEX proposal should clearly show that risk has been sufficiently mitigated to limit the potential for cost overruns.**

While universities and research institutes may receive a substantial percentage of PRODEX funding for an instrument, that funding may also reach industry through direct purchase or small scale development. This is often not appreciated outside the institutes and rarely quantified.

– **RECOMMENDATION: Records of the funding of smaller contracts via the institute funding contribution from PRODEX should be maintained by the institute.**

SCIENTIFIC EXPLOITATION (INCLUDING SNSF)

In general, laboratory preparations and scientific exploitation is funded through grants from the Swiss National Science Foundation (SNSF). These grants provide PhD students and Post-Docs for analysis, publication, and other forms of data exploitation. The level at which this funding is allocated is decided via proposal review. It is also an appropriate division of funding mechanisms – the PRODEX scheme funds hardware developments and associated data-related products while SNSF funds scientific exploitation of the data.

While SNSF has, in the past, been invited to participate in Swiss PRODEX proposal reviews, this has not implied any subsequent commitment from SNSF to fund scientific activities associated with the hardware provision. Given that instrumentation development for a mission can require a 15+ MEuro investment, the absence of a means of guaranteeing support for scientific exploitation appears rather haphazard. The system has nonetheless functioned in that, in general, experiments selected for flight are led by leading scientists in the field who are able to successfully obtain competitive research from the SNSF.

While the independence of SNSF should not be challenged and provides a scientific quality control, the magnitude of the investments being made for the larger instrument contributions suggest that the scientific exploitation should not be left unsecured. We believe that a discussion of this topic at high level should be initiated.

– **RECOMMENDATION: A review of how the scientific exploitation of Swiss instrument developments can be secured as a means of guaranteeing return on the investment is required and appropriate actions taken.**

The duration of programmes has become a serious concern. The Rosetta mission was initiated through an Announcement of Opportunity (AO) in 1994 with data from the prime mission first acquired in 2014. Close-out of the data archiving is expected in 2019 - nearly 25 years after the AO. The BepiColombo mission will have a similar duration and, in the field of astrophysics, we expect missions such as LISA to have development programmes that are longer (although flight times will shorter). A quarter of century is close to the typical time that a professor in a University can expect to hold office. As a result, transfer of responsibility to the following generation is almost inevitable. However, this also implies that the institutes need to recognize this in their hiring strategies or find alternative solutions.

– **RECOMMENDATION: Proposals to the PRODEX programme must show that the capabilities to exploit the scientific results from the proposal are present in Switzerland. It is also necessary that the persons expected to exploit the scientific results are part of the initial proposal or that scientific exploitation is ensured over the long-term should a mission extend beyond a normal academic career.**

Space-borne astronomical observatories acquire their prime science more quickly but extensions to the operational phase are usually granted unless the spacecraft or major instruments have begun to fail. For the science exploitation in these extended phases, SNSF is the usual (and appropriate) source.

INSTITUTIONAL FUNDING

Institutional funding for a programme is often misunderstood and can actually be a very significant fraction of the total funding. For a large Swiss-led project, the most senior staff may be allocating 40–50% of their time to the project through scientific, management, and public relations activities – particularly when a project hits difficulties. Depending upon the relationship to industry, the institutes may also be providing technical support to industry or indeed building an element of the hardware themselves. Some of this support may be internally funded. Finally, the institutes need to accept the hardware from industry or perform acceptance testing themselves to verify the compliance of the hardware to the specifications. Much of this work requires infrastructure that is usually not charged directly to the project and constitutes a major in-kind contribution to the project.

The degree to which institutional support contributes to the project depends upon the structure of the project itself (re-build of a simple hardware in industry may require little support for example whereas a novel instrument may require significant R&D that needs to be performed in academia if it is to be cost-effective) and the capabilities of the institution itself. It is important that the level of institutional funding towards a project is properly recognized.

EXTERNAL FUNDING

The European Commission outlined a plan for a beefed-up space research programme as part of a budget presentation in which it proposed raising the space budget to €16 billion between 2021 and 2027, an increase of about €5 billion on the present period. The most controversial part of the proposal involves creating an "EU Agency for the Space Programme". The Director General of ESA has considered this as a threat to ESA in that it would produce a "duplicate" body although some clarification on this issue has recently been made[4, 5, 6, 7]. Clearly, Switzerland has a very strong interest in the outcome of this discussion.

In addition, the European Commission now forms a non-negligible resource for space research. We note two areas in particular.

Firstly, within H2020, there have been possibilities for technology development specifically towards future instrumentation. It is difficult to obtain funding for the development of early prototypes for missions (prior to instrument selection). Some recent calls could have been used for this purpose and as such this would be welcome.

– **RECOMMENDATION: European Commission funding of space instrumentation related projects is of significant interest to the Swiss scientific community and Switzerland should support expansion of this funding.**

[4] http://blogs.esa.int/janwoerner/2018/05/31/united-space-in-europe-united-europe-in-space/
[5] www.theparliamentmagazine.eu/articles/opinion/towards-united-space-europe
[6] http://blogs.esa.int/janwoerner/2018/05/02/reflecting-on-where-we-stand-today/
[7] https://sciencebusiness.net/news/eu-denies-power-grab-european-space-agency

The ESA Science Directorate has recently proposed, as part of the preparation for the ministerial conference of 2019, that ESA funds the initial (Phase A) development of instruments for ESA missions (post-selection). This has so far been cautiously welcomed by the Member States and would help in aligning instrument development across Member States for multi-national contributions. It is important to recognize here though that additional funding would need to be given to the Science Directorate to support this. From an experimenter's perspective, the degree to which ESA then influences the hardware design/development needs to be carefully considered as this may interfere with the traditional "bottom-up approach" upon which ESA's instrument development programme is based. We also note that this is only for ESA science missions and hence developments in preparation for missions of other agencies would not be covered by this new approach.

A second area which the European Commission supports is in the exploitation of data from science missions. While these opportunities are limited, require partnerships with other EC member states, and are highly competitive, they do provide a further interesting possibility for funding.

In both cases where the European Commission is involved, the Swiss community has some concern about the stability of this source of funding. Recent experience has shown that these concerns are not without substance. However, it is recognized that the European Commission mechanisms allow strong interaction with our European colleagues in a positive competitive environment.

- **RECOMMENDATION: The European Commission provides a valuable source of funding to the space science community. Ensuring the stability of this source of funding should be a priority for the future.**

OPERATIONAL FUNDING AND DATA ARCHIVING

Missions in operation require substantial funding to ensure that instruments are operated properly and data are collected in the best possible way to support scientific exploitation. This is particularly important where Switzerland has the Principal Investigator position and is responsible (normally through signature of an Experiment Interface Document) for ensuring the data are provided to the community through a standardized archive after a specified proprietary period. The activities are neither scientific nor are they hardware-based. These include

- Updating of instrument commanding tools as needed during operation and using these tools to generate commands
- Developing strategies for optimum scientific use of the instrument
- Instrument health monitoring and taking corrective measures when appropriate
- Supporting specific "campaigns" and non-nominal operations
- Telemetry conversion and data reduction
- In-flight calibration
- Archiving of products (both low and intermediate, calibrated, level) in appropriate archives with established space standards.
- Expert centres
- Press and public outreach activities

It is important to recognize that performing these activities improves the quality of the science that can subsequently be achieved and is therefore a necessary step in maximizing the scientific return. But it is also important to recognize, that these activities are not yet "scientific" in the sense that they do not produce scientific results directly. We note that the importance of appropriate planning and budgetary support for scientific data infrastructure of this type has been flagged by the OECD in its Principles and Guidelines for Access to Research Data from Public Funding.

The current financing mechanisms for experiment development (PRODEX) and the scientific exploitation (SNSF) do not support these operations activities and has led to what has been described as a “funding gap” in the funding of experimental investigations although some mitigation efforts have been made using the Activités Nationales Complémentaires (ANC). We note that the increasing emphasis on “Open Data” now being made by the European Commission and the SNSF demands that action is taken to ensure the funding gap in the operational phase is closed.

– **RECOMMENDATION: A specific line item in the budget should be opened to allow proper funding of the operational phases of missions.**[8]

The funding needed for instrument operations must be judged on a case-by-case basis. For example, some instruments may be simpler and more autonomous than others. However, we envisage that a typical contribution might be of the order or 2-3 full time equivalent persons per instrument during the operational phase with reduced support for approximately 18 months after the end of mission to ensure that archives are populated with the best quality data set possible.

The production of higher level products is a necessary part of the data acquisition process to maximize scientific exploitation. An important initiative in this respect is the "Common Data Center Infrastructure" (CDCI). This project, led by Uni Geneva, has been included in the SBFI's Swiss Roadmap for Research Infrastructures 2015 and 2019. The CDCI provides support to space projects for their administrative, computing and software aspects. It plays also an important role in the preservation of the science gathered by these missions by providing high-level tools allowing present and future scientists to exploit the scientific results of a mission long after its termination. This initiative is being developed to support also the operational phases of hardware and software projects. The size of the CDCI is however still too limited to serve the whole Swiss space science community. On the other hand, the establishment of a national infrastructure based on the model of the CDCI could support operations and archiving and increase synergies leading to higher efficiency.

– **RECOMMENDATION: While recognizing the diversity of requirements for operations and archiving across disciplines, the effort towards the establishment of a national center to support operations of space missions should be pursued.**

To ensure clarity, it is also necessary to define the respective roles of hardware providers, operations teams, archivists, and higher level product producers.

[8] The CSR has sent a letter to the State Secretary on October 16, 2017 on this subject which pointed out the need to find a solution to cover funding for the operational phases of Swiss-led experiments.

SCIENTIFIC OPPORTUNITIES AND POSSIBILITIES

We discuss here the scientific opportunities and possibilities for future missions and development. We begin by looking at the overall context focussing on ESA and four of the major agencies outside Europe.

In general, the ESA science programme is quite transparent about its plans for the future. The funding profile likely to be proposed to the Council of Ministers meeting in 2019 (CMIN19) has been shown in Figure 8 and discussed in detail above. The programme is, for the most part, fixed by several major elements. In the 2021–2025 timeframe, the completion of Euclid (studying dark energy), JUICE (studying the Jupiter system and specifically the moon Ganymede) and PLATO (an exoplanet mission) will take priority while the 2026–2030 timeframe will be used to complete Ariel (exoplanet spectroscopy) and a possible fast mission. This will be complemented by the major build phases for the X-ray telescope, Athena, and the gravitational wave mission, LISA. The only flexibility built into the programme is through the M* element (see Figure 8), now selected as Comet Interceptor.

It should also be noted that the Human and Robotic Exploration directorate (D/HRE) offers opportunities for science (ExoMars being a prime example) but that these opportunities are part of ESA's optional programme and therefore dependent upon many countries signing up. There may, for example, be possibilities for lunar exploration through HRE after CMIN19. The technology development directorate (D/TEC) also proposes missions – the most discussed recently being the Hera mission to an asteroid that was foreseen as a possible joint project with NASA as part of the Double Asteroid Redirection Test (DART). The last Council of Ministers meeting did not approve the build of Hera and it is now unclear how this will proceed.

NASA is also transparent but the use of selection procedures means that, in many programmes, instrumentation is selected at the time of mission selection – one is either an instrument provider within the mission proposal or not. This is particularly true for Discovery and New Frontiers. In the case of the latter, there was no Swiss involvement in either of the final 2 candidates for flight (CAESAR and Dragonfly). The next Discovery round will target a launch in the 2025 timeframe with an Announcement of Opportunity in the 1st quarter of 2019. Considerable interest in this AO is being expressed by the Swiss community (specifically Uni Bern). IMAP was selected in the NASA small mission programme in the first half of 2018 and includes support from Uni Bern. Other possibilities may arise in the intermediate term. Generally, small explorers have to make compromises to stay within the financial limits. A Swiss contribution could be to enhance the mission by adding initially not foreseen subsystems. Hence, rather moderate investments on the Swiss side could result in a rather large visibility with Switzerland as a partner to a NASA SMEX mission.

In the planetary domain, JAXA is emphasizing investigation of small bodies through its Hayabusa 2 mission and its participation in the NASA New Frontiers candidate, CAESAR. In the field of space astronomy, JAXA has a long tradition in X-ray (e.g. Suzaku) and infrared (e.g. Akari) astronomy in space. For the future, their primary missions will be MMX (Martian Moons eXploration) and SPICA (Space Infrared Telescope for Cosmology and Astrophysics) for which a Swiss participation in the European SAFARI instrument has been funded. An ESA contribution in the form of a Mission of Opportunity has been approved by ESA's Science Programme Committee for MMX. In addition to these, the Japanese Institute of Space and Astronautical Science (ISAS) is currently indicating plans for an interplanetary probe demonstrator (DESTINY+), an infrared position astronomical satellite (small-JASMINE), a mission to verify the inflation theory of the

Universe by measuring the polarimetry of the cosmic microwave background (LiteBIRD) and a solar powered sail mission to study the Trojan asteroids (unnamed) (Ref: http://www.isas.jaxa.jp/en/about/vision/). We note that ESA and its Member States have recently been invited to indicate interest in participation in LiteBIRD. The X-ray mission, XRISM, is at a more advanced stage (launch in 2021) and will have Swiss participation. ESA and JAXA have negotiated a draft agreement which has recently been approved by ESA's Science Programme Committee.

ISRO is intending to launch Chandrayaan-2 (a lunar orbiter, lander and rover mission) in the near-term. The Aditya – L1 (a mission to study the Sun) is foreseen for the 2019–2020 timeframe. Their intentions beyond this are less clear although the COSPAR report on international cooperation notes that “a balanced international involvement would be a way to strengthen the science base of the future lunar and planetary ISRO missions.”

In July 2018, the Chinese Academy of Sciences announced the development of four satellites in a programme “focusing on the origin and evolution of the universe, black holes, gravitational waves and relationship between the solar system and human [sic]”. The missions are Einstein-Probe (X-ray astronomy), ASO-S (solar physics), SMILE (solar wind-Earth magnetosphere interaction) and GECAM[9] (gravitational wave astronomy). Collaboration with European institutions on at least two of these missions (Einstein-Probe and SMILE) have been brought up at high level within ESA. In addition, the Chinese programme to study the Moon continues. Chang'e-4 (now named Queqiao) entered its planned orbit successfully after launch in May 2018. The CNSA web site notes “the lander and rover of Chang'e-4 will be equipped with instruments developed by Germany and Sweden. China's lunar exploration program [sic] will be a new research platform for scientists around the world.” Further missions in this programme are to be expected. Participation in these programmes appears possible and could support research interests at several institutions. Further missions such as eXTP and HERD are being actively discussed.

The Roscosmos scientific programme is limited at present to support of the ExoMars Rover mission, the Luna Glob/Resurs missions, a return to Venus and the World Space Observatory. The future beyond these missions is at present unclear. The schedule for some of these missions may be somewhat uncertain.

[9] www.cnsa.gov.cn/n6443408/n6465652/n6465653/c6802251/content.html

SPECIFIC PROGRAMMES BY SCIENTIFIC DOMAIN

IN SITU INVESTIGATION OF THE SOLAR SYSTEM AND ITS ENVIRONMENT

The investigation of our Solar System using interplanetary spacecraft has been one of the major areas of Swiss excellence over the past 50 years. The key themes in recent years have been

- Investigation of comets and their relationship to the origin and evolution of the Solar System
- Investigation of Mars and its past and present evolution through orbital remote sensing and surface science
- Investigation of the Jovian system through in situ measurement
- Investigation of the exosphere and structure of Mercury as an end-member in our Solar System

Within the period 2019–2024, there are several ESA Solar System missions expected to launch and/or be in prime mission. These include

- BepiColombo – The ESA/JAXA mission to investigate our innermost planet, Mercury (launched 20 October 2018)
- The ExoMars Trace Gas Orbiter – The ESA/Roscosmos mission to study the atmosphere-surface interaction of Mars (launched 2016 and now in prime mission)
- The ExoMars Rover – The ESA/Roscosmos mission to explore Mars's sub-surface and its potential for sustaining life (launch 2020)
- JUICE – ESA's mission to study the Jovian system with special emphasis on Ganymede (launch 2022)

All these missions have strong Swiss involvement that has already been selected and started prior to the time of writing. Funding through the SSO/PRODEX has in general already been approved through to the end of Phase D.

In addition, there are several missions of other agencies to which Switzerland contributes. These include NASA's Insight to study the internal geophysics of Mars (launched 2018) and the Roscosmos missions Luna Glob and Luna Resurs (launches in 2021 and 2023). Other involvements are collated in the COSPAR report of 2018 [1].

Many of the scientific aspects will remain of interest to the community in the coming decade while data from missions such as ExoMars, BepiColombo, JUICE and, to a lesser extent, Rosetta, are exploited. We also envisage that Mars will remain a topic of investigation and exploration well beyond the ExoMars rover mission. Here, sample return is high on the agenda of NASA and ESA and this may result, at some stage in the near future, in a multi-billion Euro endeavour in which many nations could participate. The options for scientific participation in such a programme are, as yet, unclear and may depend heavily on the success of ExoMars and/or NASA's Mars 2020. Nonetheless, a sample return may become a reality towards the end of the next decade and it is scientifically and politically important that Switzerland plays a visible role.

We also point out that scientific investigations from orbit should still be performed. The need for high spatial resolution spectroscopy and IR imaging of the surface to define mineralogical relationships over much of the planet has been identified in previous instrumentation calls as being scientifically critical to understanding Mars evolution and we envisage that a Mars exploration programme will continue on both sides of the Atlantic.

- **RECOMMENDATION: Switzerland should continue to play an active role in Mars research including active participation in any Mars sample return programme. The activities should also include consideration of participation in further remote sensing activities at Mars to provide global context.**

For the future, there are three other areas where scientific interest would be large. They are

- The outer Solar System from Jupiter to beyond
- The lunar regolith and what lies below
- Small bodies and particularly comets

While ESA's JUICE mission will ensure that the Jupiter system remains a key scientific goal for the next decade, further impetus will arise as a result of NASA's ongoing commitment to studying Europa and the prospect of Discovery missions to the Jovian system being feasible again. NASA's programme is already providing further opportunities for outer Solar System studies. We note that Uni Bern is involved scientifically in NASA's Europa Clipper mission and is actively supporting a Discovery mission proposal to Jupiter's volcanic moon, Io, with the emphasis on providing a hardware element. There are further studies for a Europa lander to complement Europa Clipper. Uni Bern has been invited to participate in 2 different instrument consortia for what will be an extremely challenging mission. The possibility of participating in one or more of these massively exciting opportunities should not be closed.

ESA has recently proposed to include a Uranus/Neptune element as a joint mission with NASA within its proposal to the ministerial conference of 2019. The expected launch date would be in the 2030 timeframe. There is significant interest in a mission to the icy giants from Uni Zurich and Uni Bern because of their importance in Solar System formation studies, the physics of the planetary interiors and the processes associated with their moons and magnetospheres. Should this mission materialize as a result of additional money being provided to the Science Programme, we would envisage a strong interest from the Swiss community to participate including provision of flight hardware.

Studies of the Moon are becoming increasingly relevant as agencies discuss whether the Moon should be used as a stepping towards further exploration goals. The activity of the Russian and Chinese agencies in this field should be noted. Swiss teams have a scientific interest in this subject and have been involved in the development of hardware (Luna Resurs/NGMS) but are also strongly interested scientifically in looking at surface and sub-surface water and other potential resources through spectroscopic studies in the lab. Hence, should the Moon become a key element in future exploration plans, the expertise to participate in this field is available.

Small body research remains of interest following the Rosetta mission and a strong community in Switzerland exists. New missions have been proposed (at present within the F-class category) and continued activity in this field would have considerable support in Switzerland.

HELIOPHYSICS AND INTERSTELLAR BOUNDARY PHYSICS

The joint NASA-ESA mission SOHO was launched in 1995 and after 23 years of operations some of its experiments are still operational. Among them is the solar irradiance experiment VIRGO built by PMOD/WRC, which is measuring the variations of the solar irradiance. VIRGO contributes the longest time series from a single instrument to the 39-year composite of measured solar irradiance from space. By assessing the impact of SOHO there is no doubt that this mission was a major milestone for advancing our understanding the Sun and the interplanetary medium, the heliosphere. However, many key questions remain unanswered:

- How does the Sun create and control the heliosphere?
- How and where do the solar wind plasma and magnetic field originate in the corona?
- How do solar transients drive the heliosphere variability?

- How do solar eruptions produce energetic particle radiation that fills the heliosphere?
- How does the solar dynamo work and drive connections between the Sun and the heliosphere?

These questions are expected to be addressed by the upcoming ESA mission Solar Orbiter, which is named after its unique highly elliptic orbit that will approach as close as 0.8 AU to the sun and will in its perihelion phase co-rotate with the solar rotation. This quasi-hovering vantage point over the rotating sun will allow to focus longer on specific features on the sun, then it possible from a terrestrial viewpoint. In addition, Solar Orbiter will in the course of its lifetime leave the ecliptic plane and will eventually reach an orbit, which is inclined by 30° to the ecliptic. This will make it possible, for the first time, to have good views of the solar poles that will allow to address scientific questions related to polar features.

There are Swiss participation and hardware contributions in three Solar Orbiter experiments, namely STIX, SPICE, and EUI. For the STIX experiments the FHNW is PI institution and this instrument is viewed as the "Swiss instrument" on the mission. The PMOD/WRC has contributed hardware to the other two experiments that are led by ESA in the case of SPICE, and by ROB in the case of EUI. As already pointed out above, as for all other Swiss space experiments, the operational phase of the solar orbiter instruments is not covered by the PRODEX funding and there will be an urgent need to identify a funding line for the operational phase in particular for the Swiss PI instrument, STIX.

In addition to the ESA mission Solar Orbiter there are several heliophysics missions by other agencies to which Switzerland contributes. These involvements are described in more detail in the COSPAR report of 2018 [1]. SMILE (Solar wind Magnetosphere Ionosphere Link Explorer), for example, is a joint science mission between ESA and the Chinese Academy of Sciences (CAS) with a planned launch in 2023. The Science Management Plan has recently been approved by ESA's Science Programme Committee. The mission will investigate the interaction between the solar and the Earth's magnetosphere by providing global imaging in X-ray and UV. FHNW has the responsibility of the thermal design and the thermal radiator of the Soft X-ray Imager (SXI), and will be involved in software development.

For the next decade in heliophysics, there will be emphases on the space safety aspect, which requires the monitoring of the space environment including the ultimate origin of the activity, the Sun. ESA plans to cooperate for this purpose with NASA in that each agency contributes a complementary mission. NASA intends to place a mission on the line between the Earth and the Sun, in the so-called Lagrange point L1, to have the capability of measurement in-situ the solar wind heading to Earth. ESA will contribute a mission in the so-called Lagrange point L5, from which the solar side can be viewed, which is orbiting into facing the Earth, in order to see in advance the origins of active regions from which, potentially, mass ejections could be impacting Earth. The PMOD/WRC is already involved in the phase A design of a UV imaging experiment for the Lagrange remote sensing mission.

Since more than a decade the scientific community is discussing a mission that would fly over the poles of the sun in order to have the best possible view on the solar poles, which are understood to be of particular importance for the solar activity cycle. Up to now, none of several proposals has been selected but it is anticipated that the next heliophysics science mission after Solar Orbiter will be a mission with an orbit over the solar poles. PMOD/WRC has been involved in several proposals to ESA and JAXA, proposing a mission for viewing the solar poles and presently, it is partner in a proposal for a NASA MIDEX mission.

TABLE 1 Solar system missions with Swiss participation where national funding would be needed post – 2019. Note that dates in the future are approximate and will usually be dependent upon mission lifetime and extensions.

Mission/ Experiment	Phase B entrance date	Launch	Start main data phase	Comple-tion	Current activity	Size of participation S	M	L	Type of participation
Projects that have reached Phase B prior to 2019									
Rosetta/ ROSINA	1996	2004	2014	~2022	Science, archiving			X	Hardware
InSight/SEIS	2010?	2018	2018	~2024	Science, operation		X		Hardware
TGO/CaSSIS	2013	2016	2018	~2024	Science, operation			X	Hardware
BepiColombo/ BELA	2008	2018	2024	~2029	Operation			X	Hardware
BepiColombo/ SERENA	2008	2018	2024	~2029	Operation		X		Hardware
ExoMars/CLUPI	2015	2020	2021	~2023	Build		X		Hardware
Luna-Glob/ LASMA	2013	2021	2021	~2022	Build	X			Hardware
LUNA RESURS/ NGMS	2013	2023	2023	~2024	Build			X	Hardware
JUICE/PEP	2015	2022	2028	~2032	Build			X	Hardware
JUICE/GALA	2015	2022	2028	~2032	Build	X			Hardware
JUICE/SWI	2015	2022	2028	~2032	Build	X			Hardware
Projects expected to be selected and enter Phase B in 2019 – 2023 timeframe									
F-class mission (Comet Interceptor)	2020	2026/8	2030	2034	Design		X		Hardware (1 of 6 in current down selection)
Projects expected to enter Phase B in 2019 – 2023 timeframe (proposed or likely to be proposed)									
Io Volcano Observer/INMS	2022	2027	2032	2035	Proposal		X		Hardware
Europa Lander/C-LIFE	2022	2028	2033	2035	Proposal		X		Hardware
Europa Lander/ Mass spec.	2022	2028	2033	2035	Proposal		X		Hardware (2 competing proposals only 1 of which can fly)
M* (Uranus/ Neptune)	2023	2030	2038	2040	Proposal			X	Hardware (TBD)
Possible projects entering Phase B post – 2023									
EnVision (M5)	2024	2032	2033	2037	None	X			None
F2	??	??	??				X		Unclear

TABLE 2 Current and prospective missions in the heliosphere domain.

Mission/ Experiment	Phase B entrance date	Launch	Start main data phase	Comple-tion	Size of participation			Type of participation
					S	M	L	
Projects that have reached Phase B prior to 2019								
SOHO/Virgo/ CELIAS	1991	1995	1996	On going		X		Hardware, calibration
RHESSI	1999	2002	2002	2018		X		Hardware, software
IBEX	2005	2008	2009	~2020	X			Calibration
NorSat-1/CLARA	2012	2017	2017	On going	X			Hardware
PROBA2/LYRA	2004	2008	2008	On going	X			Hardware
PROBA3/DARA	2010	2020	2020	2024	X			Hardware, calibration
FY-3E/DARA-JTSIM	2012	2020	2020	2024	X			Hardware, calibration
Solar Orbiter/STIX	2010	2020	2022	2027			X	PI, hardware
Solar Orbiter/SPICE	2010	2020	2022	2027		X		Hardware
Solar Orbiter/EUI	2010	2020	2022	2027		X		Hardware
IMAP	2018	2025	2022	2030	X			Calibration
SMILE/SXI	2018	2023	2023	2026				Hardware
ASO-S/HXI	2018	2023	2023	2028	X			TBD
Projects expected to be selected and enter Phase B in 2019–2023 timeframe								
FOXSI (NASA SMEX)	2019	2023	2023	2015				TBD
SOLARIS (NASA MIDEX)	2021	2025	2026			X		Hardware

SPACE SAFETY

Space Safety will become a distinct ESA programme in the near future. There is a strong interest of Uni Bern, PMOD/WRC, and EPFL to participate in the activities of this programme and, in particular, in the following domains:

- Hosting of the ESA Expert Centre for optical and laser observations at the University of Bern
- The Lagrange remote sensing mission of the Space Situation Awareness department within D/OPS to which PMOD/WRC intends to make a hardware contribution
- Observation and modelling of the space debris environment
- Development of sensor technologies for ground-based optical and laser sensors for space object observations
- Development of a space-based optical instrument for debris detection, including the on-board and on-ground processing software
- Development of low cost space debris removal systems

CleanSpace One [10] is a technology demonstrator designed to de-orbit the SwissCube cubesat launched in 2009. While not formally a science mission, the developed technology might ultimately contribute to the space safety theme. The mission is currently in a funding consolidation phase. Nevertheless, technology developments are on-going and have been focused on the critical technologies such as the detection strategy, the rendezvous sensors and on-board signal processing (to bring smarts and autonomy to the satellite), and the capture system. One aspect of this mission is the development of technologies that might be used for other purposes. 3D LiDARs, for example, can be used to range to space debris but also have multiple uses for exploration and potentially for science (e.g. surface rovers). Coordination of efforts in this domain might be beneficial.

TABLE 3 Current and prospective missions in the space safety domain

Mission/ Experiment	Phase B entrance date	Launch	Start main data phase	Completion	Size of participation S	M	L	Type of participation
Projects expected to enter Phase B in 2019–2023 timeframe								
Lagrange-RMS	2020	2024?	2025	2030		X		Hardware

[10] espace.epfl.ch/spaceresearch/cleanspaceone_1

SPACE ASTRONOMY

The investigation of our Universe using ground-based and Earth-orbiting telescopes has been one of the major success stories in the Swiss science. The key themes in space-based astronomy in recent years have been

– Detection and characterization of planets orbiting other stars
– Determination of the structure of our Galaxy
– Study of the origin, composition and fate of the Universe
– Investigation of the Universe through high energy astrophysics
– Opening of a new "window" in astronomical observations through the study of gravitational waves

Once a space observatory is launched, its lifetime can be considerable. For example, HST has been operational for more than 30 years while XMM-Newton is still active 18 years after launch. Consumables (e.g. coolant for infrared observatories) may restrict this lifetime in some cases but continued operation of observatories such as XMM-Newton and INTEGRAL have enormous benefits to the science community as illustrated by the detection of the gravitational-wave event GW170817 by INTEGRAL after the initial evidence was presented by gravitational wave detectors. While scientific exploitation for these and other missions with Swiss hardware participation currently in orbit (e.g. AMS-02) is funded through the SNSF (with some institutional support), Switzerland contributes to the ground segment of INTEGRAL and Gaia through dedicated support from the SSO, ESA (for INTEGRAL) and Uni Geneva. The maintenance of support for the operational activities of these missions is a significant but necessary commitment.

TABLE 4 Current and prospective missions in the space astronomy domain

Mission	Phase B entrance date	Launch	Comple-tion	Current activity	Size of participation S	M	L	Type of participation
Projects that have reached Phase B prior to 2019								
XMM-Newton	1993?	1999	~2027	Science	X			Hardware
INTEGRAL	1996?	2002	~2021	Science, operation			X	Ground-segment
Gaia	2007	2013	~2022	Science, operation			X	Ground-segment
AMS-02	2008	2011	~2021	Science			X	Hardware
JWST/MIRI	2009?	2021	~2031	Build		X		Hardware
Hitomi	2011	2016	2016	Science	X			Hardware, ground-segment
POLAR	2012	2016	2017	Science	X			Hardware
Euclid	2012	2022	2028	Build		X		Hardware, ground-segment
DAMPE	2013	2016	~2021	Science		X		Hardware
CHEOPS	2013	2019	~2024	Build			X	Hardware, ground-segment
K-EUSO	2013	2024	~2028	Build	X			Hardware
Plato	2017	2026	~2032	Build		X		Hardware
XRISM	2018	2021	~2026	Build	x			Hardware
Projects expected to enter Phase B in 2019–2023 timeframe								
miniPAN/PAN	2019	2022	?	Design	x			Hardware
Polar-II	?	?	?	Design	x			Hardware
HERD	2020	2025	~2030	Design	X			Hardware
eXTP	2020	2025	~2030	Design	X			Hardware, ground-segment
Athena	2021	2030	~2040	Design			X	Hardware, ground-segment
LISA	2021	2034	~2044	Design			X	Hardware, ground-segment
THESEUS (M5)	2022	2032	~2042	Design		X		Hardware, ground-segment
SPICA (M5)	2022	2032	~2042	Design		X		Hardware, ground-segment
F-class mission	2020	2026/28	2034			X		Hardware?
Possible projects entering Phase B post–2023								
F2	??	??						

Switzerland has made several significant contributions to the Chinese programmes, DAMPE (launched in 2015) and POLAR (a polarization-sensitive X-ray detector that was installed on the Chinese Space Station Tiangong-2 in 2016). In both cases, current Swiss participation is restricted to science exploitation funded through Uni Geneva and SNSF.

Within the period 2019 – 2024, there are several major ESA missions with large Swiss contributions expected to launch. These include

- CHEOPS (the Swiss satellite to determine mass-radius relations for exoplanets)
- JWST/MIRI (the replacement for Hubble Space Telescope)
- Euclid (ESA's new mission designed to search for the origin of dark matter and dark energy)

These will attempt to answer some of the fundamental questions in astronomy that include

- What is the nature of dark matter and dark energy?
- What fundamental properties can the study of gravitational waves reveal about our Universe?
- What processes lead to the diversity of planetary systems now being revealed by observation?

CHEOPS is co-led by Switzerland and with a Swiss contribution that is much larger than is foreseen in the future for Swiss involvement in small missions. This is justified, however, in that CHEOPS is a national project with the participation of several astronomy institutes in Switzerland. The mission is also of high strategic significance as befits a science effectively started in Switzerland by Mayor and Queloz.

ETH Zurich will be involved in the upcoming project phases of JWST and provides staffing effort to the mission control centre at STScI in Baltimore during the commissioning phase of JWST. Launch is now expected in 2021. The awarded 450 hr of GTO will be shared among the Consortium in a collaborative manner. ETH Zurich will be part of the exoplanet and of the protoplanetary science programs that consume roughly 50% of the total GTO. Additionally, due to the gained instrumental expertise, submission of competitive proposals for open observing time to follow up some of the observations conducted as part of the GTO are planned.

Euclid will be launched in 2022 and has significant Swiss participation. This comprises the development of a shutter for the VIS instrument, led by Uni Geneva, and a strong participation in the ground-segment, led by Uni Geneva supported by FHNW and EPFL. Uni Zurich also plays a role by running cosmological simulations necessary to test the performance of the analysis pipelines. The science participation is supported by an SNSF Sinergia programme.

Several missions in collaboration with other agencies are also expected to launch within the 2019 – 2024 period. XRISM, the X-ray Imaging Spectroscopy Mission, is a mission led by JAXA with strong NASA participation and a smaller ESA contribution through a Mission of Opportunity program. XRISM, which is planned for launch in 2021, is being developed as a replacement for the Hitomi mission, which failed six weeks into operations. Uni Geneva contributed to Hitomi by providing the filter wheel subsystem of the SXS, together with SRON, the Netherlands Institute for Space Research. A similar contribution for XRISM is on-going to recover Hitomi science and will pave the way for the next large X-ray observatory, ESA's Athena.

K-EUSO is a former Japan-led and currently Russia-led instrument to be installed on the International Space Station in 2024. K-EUSO consists in a 2.4m-diameter telescope that observes the earth's atmosphere in order to detect flashes of light caused by the penetration of ultra-high energy cosmic rays. Uni Geneva has contributed by working with CSEM to develop a laser-pointing system for the LIDAR needed to monitor atmospheric properties.

Several missions of importance to Swiss astronomers are already in development for launch in the 2025–2030 timeframe. From a Swiss perspective, ESA's Plato is the most significant. It combines a number of small, optically fast, wide-field telescopes to detect exoplanet transits over a wide field-of-view, with the goal to detect earth-like exoplanets around solar-like stars. Uni Bern will provide the mechanical structure to support the individual telescopes. The Uni Bern-Uni Geneva collaboration in exoplanets will be furthered by Uni Geneva contributing to the follow-up of exoplanet candidates.

Two other missions have started at top level with Phase B proposals for Swiss participation yet to be made. POLAR-II, which is essentially a rebuild of the Polar instrument that has been flown on the Chinese Space Station. Uni Geneva is interested in this rebuild, which is strongly encouraged by the Chinese Manned Space Agency. eXTP is the next flagship mission in the Strategic Priority Space Science Program of the Chinese Academy of Sciences. eXTP is scientifically the successor of the LOFT project, proposed to the M3 and M4 calls of ESA. A significant Uni Geneva contribution had been envisaged. eXTP will study the state of matter under extreme conditions of density, gravity and magnetism in the X-rays. Primary targets typically include neutron stars and black holes. eXTP is of strategic importance to Uni Geneva as it sits temporally between the the XRISM and Athena missions. It is expected to be included as a Mission of Opportunity within ESA's Science Programme within the next two years.

Two other Chinese missions of interest in this timeframe are HERD and ASO-S. HERD is an instrument for the Chinese Space Station and is currently under review by the Chinese Manned Space Agency. HERD will observe cosmic rays up to very high energies, in particular maintaining high acceptance in the "knee" region, around the petaelectron-volt and gamma-rays from 50 MeV to GeV with unprecedented spatial resolution and sensitivity. Uni Geneva is considering a contribution to the particle tracker of HERD using scintillating fibers and silicon photomultipliers.

ASO-S (Advanced Space-based Solar Observatory) is the first Chinese Mission dedicated to solar physics studies and it will explore connections among solar magnetic field, solar flares, and CMEs. FHNW is currently involved as a consultant to the Hard X-ray Imager (HXI), with possible hardware contributions being discussed. The main scientific driver for a collaboration with the ASO-S team is the potential of having joint stereoscopic observations with the FHNW's STIX instrument onboard Solar Orbiter.

miniPAN and PAN are proposed missions for the Deep Space Gateway to develop cosmic ray particle detectors. The development, led by Uni Geneva, might, in the future, be supported by the H2020 SPACE call of the European Union.

Although more than a decade prior to launch, planning and design for several major missions in the astronomy field has started and Swiss contributions are already being defined.

Athena is the second large mission L2 of ESA's Cosmic Vision programme. It will be the largest X-ray telescope ever built, and will embark revolutionary instruments like an X-ray cryogenic micro-calorimeter, with two orders of magnitude higher imaging capabilities than Hitomi and XRISM. It is currently planned for launch in 2030. Athena is an evolution of the XEUS and then IXO concepts, and is the long-term strategic mission for high-energy astrophysics in space. UNIGE is leading the Swiss contribution to Athena, with a hardware contribution to the calorimeter and significant ground-segment contributions to both instruments. The Swiss contribution is planned to be at the level of a large mission.

Theseus and SPICA are both medium-class down-selected candidate missions for the M5 slot of ESA's Cosmic Vision programme. Theseus will explore the explosions in gamma-ray bursts of the first stars at the cosmic dawn of the Universe. The launch would be in 2032. Uni Geneva is participating with a contribution to the infrared spectrometer needed to measure instantaneously the redshift of the exploded star and a contribution to the ground-segment. SPICA will explore the mid-to-far infrared Universe with a cryogenically cooled telescope. The launch would also be in 2032. Uni Geneva participates here in a hardware contribution for the SAFARI instrument and leads the SAFARI Instrument Control Center. For both missions, the Swiss contribution is planned to be at the level of a medium mission. It should be noted that the other M5 candidate, EnVision, is in the planetary domain and has no contribution from Switzerland at this time.

LISA is a space-based gravitational-wave observatory to be launched in 2034 as the third large mission of ESA's Cosmic Vision programme. Gravitational wave science received a Nobel Prize in Physics in 2017 and is strongly represented in Switzerland. ETHZ participated in the highly successful LISA Pathfinder mission and INTEGRAL made a major contribution in detecting electromagnetic counterparts of gravitational wave events. Building upon this, ETHZ plans to make a significant hardware contribution to LISA. Uni Geneva plans a moderate contribution to the ground segment activities. Scientifically, Uni Zurich, ETHZ and Uni Geneva are planning significant contributions. The hardware contribution could potentially exceed the level currently assumed for a large (L-class) mission.

In the cases of missions such as Athena and, in particular, LISA, the start of initial developments may be 20 years before a demonstrable scientific result is obtained. Following the JWST experience, it is now apparent that multi-decade mission developments are no longer solely to be found in the Solar System domain. It is apparent that long duration developments challenge the hiring policies in some institutions when a project leader retires. It should be consider how this might be resolved within the Swiss system. For example, can a project have a hardware development carried out in one organization and then be passed across to another for data acquisition and analysis? There may be other ways of managing knowledge transfer over generations without compromising the fundamental goals (such as hiring policies) of the institutions.

– **RECOMMENDATION: In view of its novelty and pioneering research aspects, the appropriate structural actions should be taken to secure the long term support required for a Swiss participation to the LISA L3 mission hardware.**

– **RECOMMENDATION: A review of the relationship between institutes developing space technologies and those performing scientific exploitation should be made to identify synergies and establish possible methods for knowledge transfer across scientific generation boundaries.**

The close links between space-borne astronomy and ground-based astronomy cannot be underestimated and therefore a formal communication between the Commission for Space Research and the Swiss Commission for Astronomy should be maintained and further developed.

– **RECOMMENDATION: The communication between the Commission for Space Research and the Swiss Commission for Astronomy should be furthered to take advantage of all synergies within the Swiss astronomy community.**

SPACE-BORNE MEASUREMENTS OF PHENOMENA REQUIRING MICRO-GRAVITY

The next phase of the manned space program implies missions that exposes humans to the space environment (e.g. microgravity, enhanced cosmic radiation) much longer than before. Therefore, ensuring good health of the space travelers will become a central aspect of the space program in the upcoming years. So far, the major interest of space medicine was to determine the changes that occur in the human body while in space and the outcome points to substantial changes on cellular, tissue, organ, and even whole body level. In a next phase, efficient countermeasures are needed to stop or reverse the negative effects of space exposure. The focus of space medicine thus has to shift slightly. But because the quality of countermeasures depends heavily on a thorough understanding of the underlying biomedical processes, basic research in space biomedicine is inevitable.

A major output of the biomedical research in space is that most of the negative effects determined are similar to those induced by the ageing process naturally occurring in people on Earth. This opens-up new possibilities in gerontological research through microgravity experiments for example. Furthermore, gaining new insights in biomedical mechanisms, even induced by space exposure, deepens our understanding for biology and medicine in general. Therefore, research in space medicine is not only beneficial for a few astronauts but also for patients on ground.

Research in space medicine does not relay on particular orbits or places in space. Reliable scientific data on low gravity effects can be produced wherever a microgravity environment is present. This can be achieved in drop towers, through parabolic flights manoeuvers by an airplane, on board sounding rockets or the International Space Station. There are even devices available to simulate microgravity in laboratories on ground. The results gathered with these devices however do not replace the experiments in space. It is therefore important to access space borne research platforms, either on low orbit or further out in space. At some point, it will also be necessary to conduct biomedical experiment under partial gravity conditions like on Moon or Mars in order to make reliable predictions on how long-term visits of humans on celestial bodies with a gravity environment different to Earth will impact health.

TABLE 5 Past, current and prospective experiments in the space biology domain

Name	Type	Facility of the International Space Station used	Flown
Space Incubator	Culture chamber for human or animal cells (batch config.).	Stand alone	1983, STS-8, STS-9, and 1991, STS-40 Spacelab module
Dynamic Cell Culture System (DCCS)	Culture chamber for plant, animal and human cells. Completely self-contained system.	KUBIK	1992, STS-42, IML-1
Sophisticated BioReactor (SBR1 and SBR2)	Miniaturized bioreactor with all the functionalities of a standard commercial biore-actor model.	KUBIK	SBR1: 1994, STS-65 and 1996, STS-76
SBR2: 2003, STS–107			
Codi-Module	Bioreactor for tissue engineering; especially designed for in-vitro cultivation of cartilage cells.	Currently no facility avail-able in the ISS.	2002, MASER 9 sounding rocket
Investigation Chamber (IC)	Culture chambers, Type I container	KUBIK	2003, STS–107
LEUKIN1	Culture chambers, Type I container	KUBIK	2003, STS-107, Spacehab
LEUKIN2	Culture chambers, Type I container	KUBIK	2006, ISS "Astrolab" - long-duration mission and ISS 13S (Soyuz TMA-9)
PADIAC	See Space Incubator. Fitting into Type I container.	KUBIK	2010, ISS Increments 25-26
SPHEROID	Cell culture chamber	Stand alone	2016, ISS Increments 47-48
YEAST BIOREACTOR	Combination of the SBR and the IC.	European Modular Cultivation System (EMCS), TBC	In 2020

Switzerland has a long history of working on biology in space themes. This began with Space Incubator on Skylab to investigate the response of human lymphocytes to a mitogen during space flight and to determine functional changes occurred in the cells responsible for the immune response. The Dynamic Cell Culture System (DCCS) in 1992 was designed to develop and test an automatic cell culture system (DCCS) for long-term cultures of mammalian cells in space, and to investigate the behaviour of hamster kidney cells, cultured in the DCCS, with respect to cell proliferation, production of tissue plasminogen activator (t-PA) and cell metabolism in microgravity. Subsequent experiments have looked at the necessary properties of bioreactors and culture chambers and how leukocytes (white blood cells) are activated and how Interleukin-2 (IL-2), a hormone that stimulates the growth of T-lymphocytes and plays an instrumental role in the body´s response to pathogens (bacteria, viruses, fungi, etc.) affects gene expression.

The latest experiment to be designed is the Yeast Bioreactor scheduled to fly in 2020. Space flight conditions affect single cell and complex multicellular organism physiology. These alterations may have important consequences for human space flights. The yeast Saccharomyces cerevisiae will be used as an excellent model organism to study the adaptation of this microorganism when grown in liquid culture medium in microgravity conditions. The project overall objective is to obtain a detailed systems biology view on the effect of microgravity on the physiology of S. cerevisiae. Different S. cerevisiae strains will be used to investigate the effect of microgravity on non-interacting and cell-cell interacting (flocculation) yeast growth, and on induced stress responses by applying a heat and osmotic shock in microgravity.

Micro-gravity can also be used to test fundamental physical principles and/or constants. The Satellite Test of the Equivalence Principle (STEP), for example, was proposed as a space science experiment to test the equivalence principle of general relativity. The experiment was thought to be sensitive enough to test Einstein's theory of gravity and other theories. In Europe, this research goal has been overtaken (or possibly even overrun) by gravitational wave astronomy. However, there remain some interesting physical constants that could be tested by future space missions although this use of space does not seem to be a priority for the community or for Swiss space scientists.

For all disciplines, we can see on-going activities where Switzerland has already made a commitment. Our place as a reliable partner rests on the completion of these activities.

– **RECOMMENDATION: The completion of the Swiss contributions to selected missions with instrumentation already committed is a necessary element of the programme and should receive high priority.**

SUMMARY OF SCIENTIFIC AIMS

Scientifically, the planning by the scientific institutes for the next few years provides a broad programme with concentrations of activity and associated excellence in a number of areas including

- Exoplanet research
- Solar system exploration (including geodesy)
- High energy astrophysics and cosmology
- Galactic structure
- Heliospheric physics and
- Micro-gravity

with the possibility of playing a significant role in the opening field of gravitational wave astronomy.

The excellence of Swiss institutes in the field of space-based scientific research, witnessed through several recent major successes, will be maintained and enhanced by supporting the future plans of the leading institutes in combination with actions to improve communication, networking, and efficiency.

SUMMARY OF THE FINANCIAL IMPLICATIONS

To assess whether the future financial requests to the PRODEX programme seen in the tables above are compatible with the availability of financial resources, we have estimated the costs to PRODEX of the missions in the above tables and produced a diagram showing the financial load with time – a so-called "waterfall diagram". In reality, the funding profiles and the timing of funding endorsement by the SSO towards ESA are considerably more complex than assumed herein and it is not our intention to duplicate the work of the SSO and/or ESA. By performing this exercise, however, we show that the projects proposed in the coming 10-15 years do not represent a financially overly ambitious programme. Rather, it shows that a relatively modest increase in PRODEX funding can lead to a solid, internationally relevant, scientific programme.

The diagram in Figure 10 is based on several assumptions that should be made clear. Firstly, the values for each project are rough estimates based on current knowledge and are therefore indicative. Secondly, projects such as IVO, M*, Theseus/SPICA, and the F-class mission, F1, have not yet been selected and the final levels of Swiss participation are estimates based on previous experience. For M*, we have assume a PI-level instrument funding (15 MEuro), for the F-class mission, an intermediate level has been assumed (8 MEuro) and for the Theseus/SPICA contribution a 10 MEuro contribution has been assumed. We stress that none of these projects has been approved. It is to be noted that the largest uncertainty here is in the planetary domain. Thirdly, a distribution of payments has been assumed consistent with the best estimate launch date at

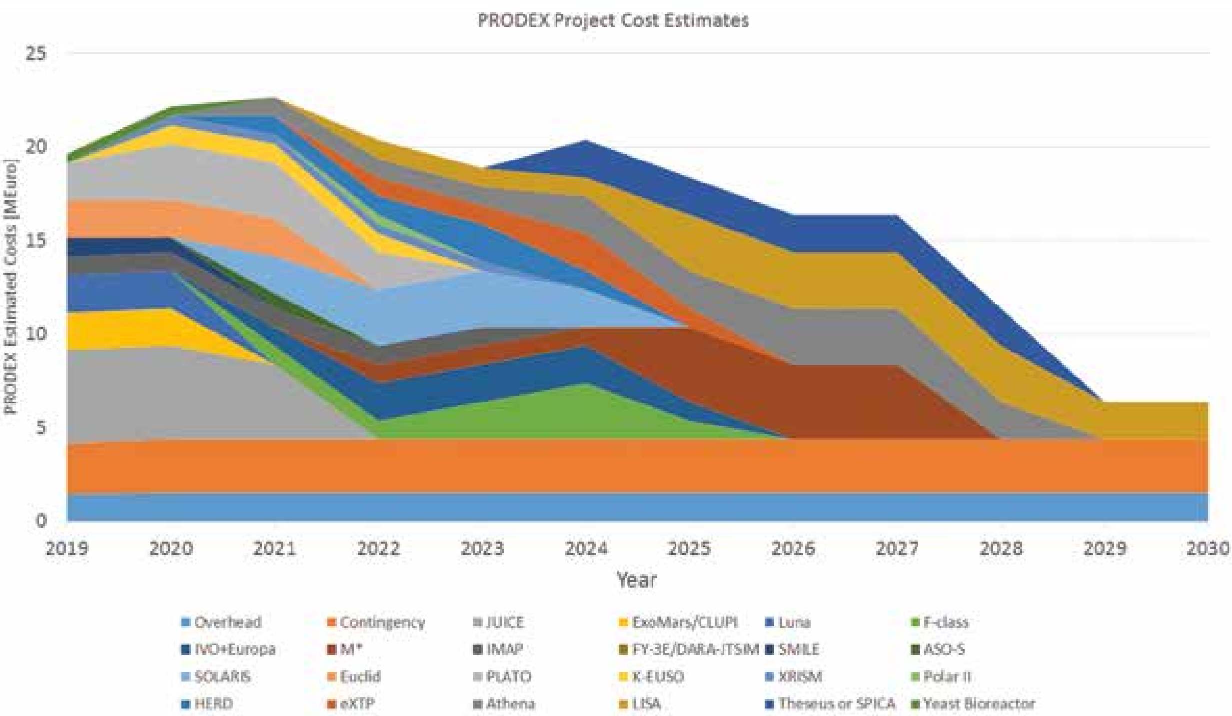

FIGURE 10 Waterfall diagram for all the projects expected to require PRODEX resources in the 2019–2030 timeframe. The estimated PRODEX budget is 19 MEuro per annum. An overhead of 8% has been assumed (paid to ESA). A 15% contingency has been included. No account of outstanding PRODEX commitments from previous years other than those noted has been made. The planned expenditure appears compatible with the expected resources in the 2021–2024 timeframe. (Credit: Nicolas Thomas)

the time of writing. In the cases of missions such as Athena and LISA with launches ~15 years into the future, there is obviously significant uncertainty. Fourthly, we have included estimated payments for JUICE, CLUPI, and LUNA although endorsements have already been issued by SSO to ESA for these programmes. Finally, an 8% overhead for ESA management of the programme has been assumed and a 15% global contingency included.

The key message of Figure 9 , however, is that the expected financial load on the Swiss PRODEX programme is only slightly higher than the resources available. Eliminating the global contingency would place the requests within the available resources (although we would not recommend this). Hence, with cost control, the proposed programme would be feasible with only a small increase in the PRODEX budget. The need to fill the funding gap for instrument-related operations is, however, not included in this assessment.

It is perhaps interesting to look at the financial resources to be allocated to individual subject areas. This is shown in Figure 10.

The diagram shows that there is a fairly reasonable balance between the major PRODEX funding consumers (heliosphere, astronomy, and planets). The following points should be noted. Exoplanet astronomy has been included in the "Planets" block here. This is a point of contention between astronomy and Solar System science and illustrates the difficulty in making a grouping of projects. Similarly, LISA is given its own line (gravitational waves) although this could easily be described as astronomy. Hence the astronomy block in this diagram could be drawn as a much larger element. The space biology element is very small in this representation reflecting the much shorter planning cycle and the lower financial needs for this discipline.

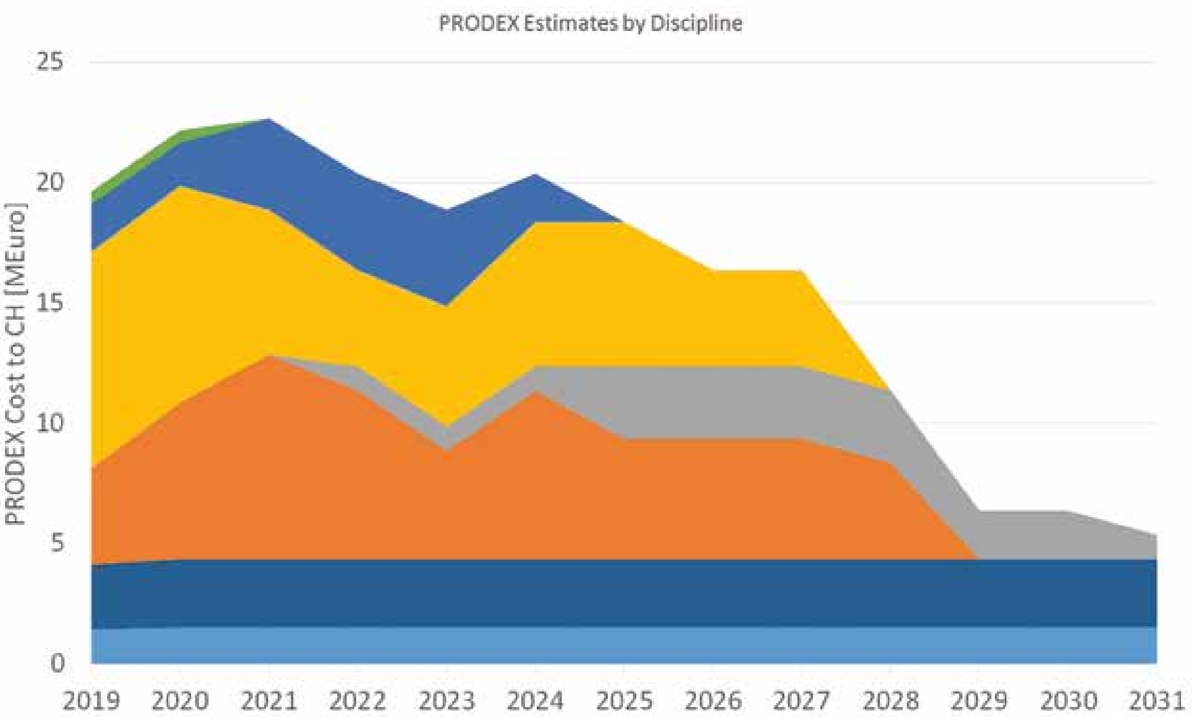

FIGURE 11 The waterfall diagram for subject areas. It should be noted that for this diagram, exoplanet astronomy has been included in the "Planets" block. This is discussed in the text. (Credit: Nicolas Thomas)

F-MISSIONS AND PAYLOAD DEVELOPMENT ACTIVITIES

ESA is currently proposing an increase in the science budget which would then include further F-class missions and payload development activities.

ESA is currently selecting F-mission candidates (<150 MEuro missions with novel approaches to data acquisition). It remains to be seen whether the scientific return justifies the outlay but institutes (including Uni Bern and EPFL) are participating in the call at this early stage. It has to be said, however, that there is considerable scepticism in the scientific community as to the effectiveness of very low cost missions (both interplanetary and astrophysics) returning high quality science. While a Swiss contribution to F1 can be envisaged, the science output may be considerably more focussed and limited than one normally expects from ESA missions. Within the proposal to CMIN 19, ESA is suggesting an F-mission programme as part of its request for a budget increase. An F2 mission (presumably to be open to the entire community) is foreseen in the 2032–2035 timeframe should the budget be approved. While one can imagine that Swiss researchers would attempt to take advantage of this opportunity, there appears to be relatively little enthusiasm at present.

Within the CMIN 19 budget request, ESA has also included a line item called Athena/LISA advance and payload support. This item is intended to offer support to member states in developing payload prior to final adoption of missions. Essentially, Phase A activities for the payload will be supported by ESA rather than through the member states. This item has advantages and disadvantages to the science community. The main advantage arises from the difficulty instrument teams have in aligning funding from different member states in the early stages of a new mission programme. Member states have different processes for allocating funding and this leads to some contributions being out of phase. ESA control at this stage is therefore of interest. The disadvantages come from an increased total cost (ESA is more expensive than Swiss institutes) and possible top-down influence of ESA on the instrument configuration to the detriment of instrument performance. The science community does not, at this stage, have a clear opinion on this issue but emphasizes that independence of the institutes with respect to ESA is an important advantage of the programme. It is also to be emphasized that science is the driver for institute participation in ESA's programme and that most institutes do not wish to be hardware providers (i.e. contractors) to ESA with no subsequent access to the science.

– **RECOMMENDATION: The Swiss Space Office should continue to ensure independence of Swiss institutes with respect to hardware provision and reject any efforts to reduce institutes to pure hardware providers.**

PRIORITIZATION AND EVALUATION

Although specialized in some areas, the Swiss space science community is broad. Comparing the relative merits of a proposal from one field with that of other proposals from different fields is often difficult. In general, however, proposed participations should foster specific groups in Switzerland scientifically. Applications should not be ranked highly unless they address topics of high Swiss scientific and/or technical relevance, currently or that can be reasonably demonstrated in the known future, taking into account the timescale of the application.

In the event of a participation being within a field new to the Swiss landscape (i.e. little or no community exists at the time of the proposal), it is necessary to establish whether Swiss entities will be in a position to give Switzerland a significant scientific visibility in this field within the timeframe of the proposed work.

Where an application is for an element within a larger consortium, it needs to be established that Swiss scientific return is commensurate with the proposed contribution.

It is often said that "ESA is Switzerland's space agency". Hence, it is clear that support of ESA mission should receive the highest priority. However, we note that missions of other agencies are important if they cover the limitations of the ESA programme. It is nonetheless critical that one should avoid direct competition with ESA.

Budgets are limited and a reasonable distribution of funds between organizations and disciplines should be sought. We note that it is dangerous to overload the programme with developments in one scientific area alone. The compensating reduction in budget for other groups may result in them dropping below a critical level from which they might struggle to recover. Maintenance of scientific capability is therefore important unless it is clear that an area is no longer at the cutting edge.

Although Switzerland's voice in ESA is not as large as the largest member states, it is heard. It is therefore important that regular consultation takes place so that the Swiss Space Office can support the interests of the Swiss community.