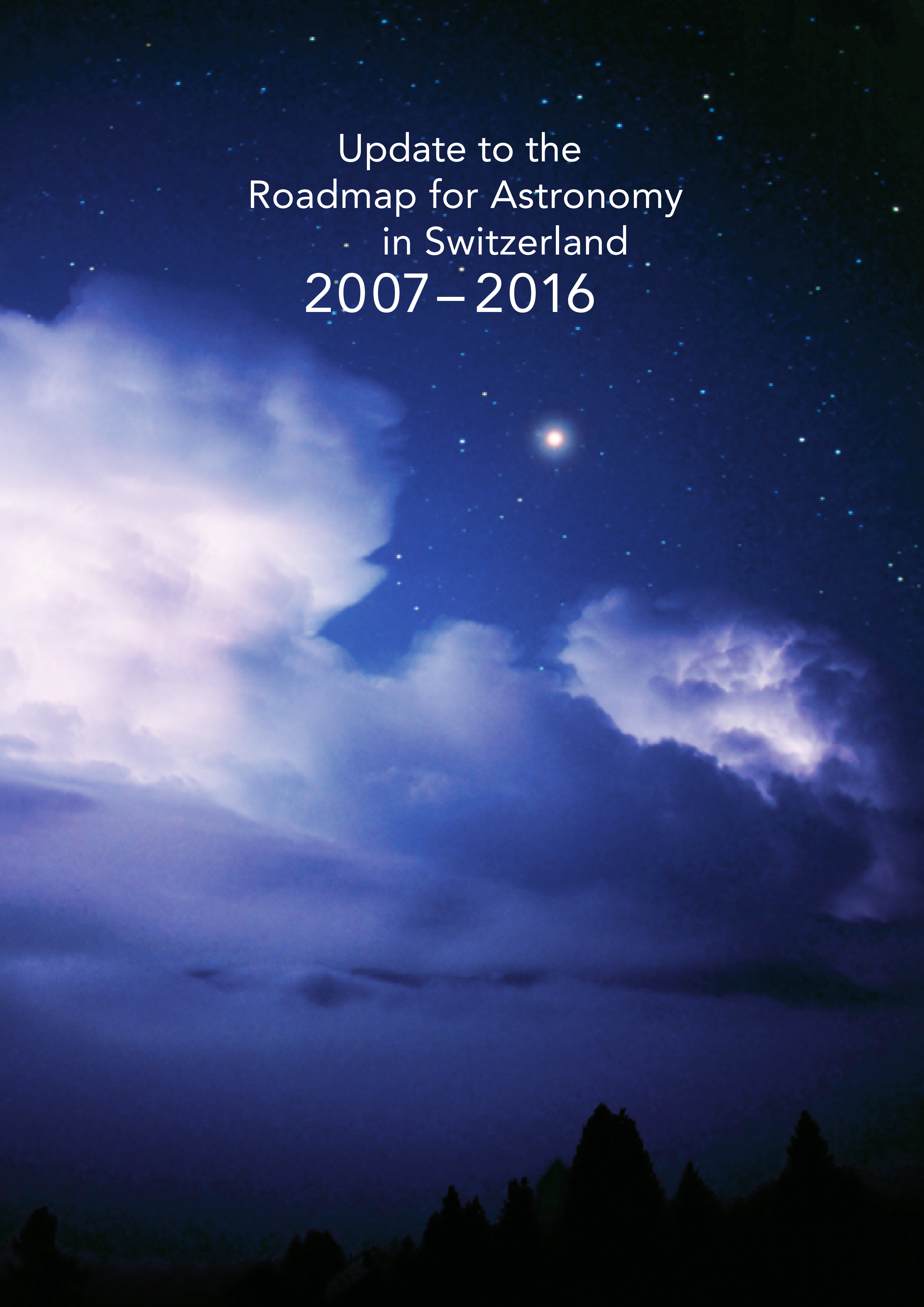
Update to the Roadmap for Astronomy in Switzerland 2007 – 2016



Update to the Roadmap for Astronomy in Switzerland 2007–2016

CHAPS (College of Helvetic Astronomy Professors)

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Executive Summary

The Roadmap for Astronomy in Switzerland 2007-2016 aimed at providing a framework in which Swiss astronomy could optimally develop by pointing out the strength of the system and providing detailed recommendations for further improving its coherence and impact. Many of the successes achieved since are directly or indirectly related to the recommendations issued at the time.

Modern space- and ground-based astronomy, with its major research infrastructures and/or platforms being planned and built within international collaborations, continues to evolve over time. Boundary conditions change and the academic and/or industrial landscape in which projects are carried out adapts. Seven years after the publication of the original Roadmap, changes have been significant enough that the need was felt for a re-assessment while awaiting the next full Roadmap foreseen for 2017.

This exercise led to a number (8) of key findings that capture key aspects of Swiss astronomy today. Each finding is followed by a recommendation. Together, these recommendations aim at continuing building the framework laid down by the 2007 Roadmap.

List of findings and recommendations

Finding 1
The breadth of Swiss astronomy is impressive and has even grown since the formulation of the Roadmap for Swiss Astronomy 2007-2016. This diversity in scientific interests calls for diversity in capabilities, realised through space- and ground-based telescopes and instrumentation, as well as in theoretical and computational developments including specialised analysis tools needed to deal with very large datasets. This diversity is also an important asset within the framework of international agencies, which set priorities for major projects. Defining a single national priority is impossible without excluding a large fraction of the astronomy community and disregarding past investments.

Recommendation 1
The diversity of astronomical research in Switzerland should be preserved through the concurrent support for participation in multiple large projects having different science goals with significant Swiss participation.

Finding 2
As future projects worldwide grow in size and complexity, significant Swiss participation in those most essential will increasingly strain available funding and make prioritisation necessary.

Recommendation 2
While scientific excellence must be the ultimate criteria, projects of equal merit should be preferred if:

a. *They establish or strengthen the scientific leadership of Switzerland in an area*
b. *They address the needs of a broad community*
c. *They are being carried out within the framework of ESA and/or ESO*

Finding 3
A strong ESO remains the greatest asset for Swiss ground-based astronomy.

Recommendation 3
ALMA in full routine operation mode, a timely and successful completion of the E-ELT with a powerful suite of instruments, and the VLT remaining a world-leading observatory in the E-ELT era remain top priorities for Swiss astronomers. Within ESO, Switzerland should continue to provide strong support for these facilities.

Finding 4
The participation by research teams in instrument building consortia enables access to significant amounts of observing time needed to maintain scientific leadership. This trend is likely to grow even more in the future, in particular with the E-ELT.

Recommendation 4
Given the size and number of instruments foreseen for the future world-leading astronomical facilities, at least a doubling of the FLARE support for astronomical instrumentation is required. Further, the rules governing FLARE should be adapted to better reflect the constraints imposed by the long-term nature of these projects.

Finding 5
Some areas of astrophysical research can be best addressed through the participation in projects taking place outside the framework of ESO.

Recommendation 5
Financial support should be made available for small to medium-size projects carried out beyond the traditional ESO boundaries. This support should be flexible in both its purpose and its use with the goal to extend research infrastructures to areas outside the main focus of ESO.

Finding 6
At present, participation in some of the new large astronomical facilities of the future is done at the level of individual research groups or through ad hoc collaborations that benefit in a concomitant way.

Recommendation 6
A federated participation by Switzerland in some of these future large projects, guaranteeing access to all researchers working at Swiss institutions, would be beneficial. Among these additional facilities, the Swiss astronomy community considers SKA and LSST as scientifically most attractive at present. It is imperative that the cost of joining one of these new projects be covered through newly available funding and not at the expense of the active Swiss participation in ESO or ESA.

Finding 7
The recent successes of Swiss scientists in proposing, and building (with the help of industry) space experiments have been such that efforts are now being funding limited.

Recommendation 7
Maintaining Swiss leadership in space sciences and technology requires an increase of 50% in PRODEX funding over the next five-year period.

Finding 8
In comparison to other countries of similar size (e.g. Belgium), Switzerland's ability to fund activities outside the framework of ESA is severely limited. In addition, funding of auxiliary technical activities (for ESA and non-ESA missions) that are not directly related to the building of experiments (e.g. software development) is also needed.

Recommendation 8
A 50% funding increase of the "National Complementing Activities" over the next 5 years is necessary.

1. Context and Background

Astronomical research is a highly competitive endeavour in which excellence is essential for progress. In such an environment, success does not come by chance. Success requires dedicated and innovative people working within an appropriate framework in which talents can blossom. The Roadmap for Astronomy in Switzerland 2007-2016 aimed at providing such a framework by pointing out the strength of the system and providing detailed recommendations for further improving its coherence and impact.

In 2007, the pressing need for a Roadmap for Astronomy was felt at government, funding agency and institute levels to:

- Plan effective investment in research projects and long duration infrastructures that carry a significant cost
- Set priorities for the future directions and facilities of the European organizations ESO and ESA
- Provide input to a European-wide vision for astrophysics
- Coordinate activities in education and outreach
- Provide a national context for decisions at the local level.

The 2007 Roadmap was prepared by the 21 elected Professors in Astrophysics at Swiss universities, plus representatives of three independent laboratories: IRSOL, ISSI, and PMOD/WRC. This was the first time that astronomy organised itself at national level to review its current activities and future ambitions in order to develop a coherent vision of astrophysics in Switzerland. CHAPS (the College of Helvetic Astronomy Professors) was established to carry out this exercise and constitutes since then the body in which these issues continue to be discussed and major priorities defined.

The Roadmap highlighted the strong foundations of Swiss astrophysics. Research groups have established international presence in many of the most current areas of research. This strength and vigorous activity provides the foundation upon which the future directions of the community can be based. The Roadmap identified four scientific themes unifying both past achievements and future potentials:

- Theme 1: Fundamental physics
- Theme 2: Origins – stars, galaxies and the evolving Universe
- Theme 3: Planets and the emergence of life
- Theme 4: Our home and the impact of the space environment on Earth.

In addition, synergies within and across these themes were recognised and encouraged as a way to breakout of the traditional research habits. Finally, in a set of findings followed by recommendations, the Roadmap identified a number of priorities and measures to maximise future impact while optimising human and financial resources.

Seven years after the publication of the 2007 Roadmap, Swiss astronomy has expanded significantly and established and/or consolidated its leadership in a number of areas (see Appendix 1). Many of these successes are directly or indirectly related to the recommendations issued at the time. These stressed the need for additional coordination and collaborations, for additional funding allowing for participation in major projects, for a strong effort in theory and computational work, to name a few. Together, these recommendations have helped build a framework that enabled Swiss astronomy to reach new heights.

Modern ground- or space-based astronomy, with its major research infrastructures and/or platforms being planned and built within international collaborations, continues to evolve over time. Boundary conditions change and the academic and/or industrial landscape in which projects are carried out adapts. Seven years after the publication of the original Roadmap, changes have been significant enough that CHAPS felt the need for a re-assessment while awaiting the next full Roadmap foreseen for 2017.

As already noted in the 2007 Roadmap, astronomy, or astrophysics, does not have sharply defined boundaries. It is intertwined with many other branches of science. Currently, there is a particularly strong synergy between particle physics and cosmology, as well as cosmic ray astrophysics and neutrino astrophysics. There are also close ties between nuclear physics and the astrophysics of stars and stellar explosions. Planetary astrophysics has strongly allied interests with geophysics while the growing interest in the development of the conditions necessary for the emergence of Life has spawned a vigorous new field of astrobiology, bringing together astrophysics, chemistry and biology. These scientific interconnections will provide much of the excitement and relevance of 21st century astrophysics. Nevertheless, to define our community and our ambitions, we are forced to limit the scope of our strategic considerations. Following the approach used in the 2007 Roadmap, these boundaries have again been set on the basis of the research methods used. As a result, we have excluded from our main considerations ground-based gamma-ray observatories, neutrino observatories, and other subjects more closely related to particle physics and/or geophysics.

To carry out the task of updating the roadmap, CHAPS appointed an editing committee in charge of preparing a draft document, which would provide the basis for the update of the 2007 Roadmap. The editing committee was also requested to proceed bottom-up and offered the community several opportunities to provide input. This exercise was carried out during the fall 2013 and through the first half of 2014 and led to the present document, which was approved by CHAPS on Oct. 1, 2014.

This image of the Cygnus X complex, taken with ESA's Herschel Space Observatory at far-infrared wavelengths, shows how young, massive stars are carving an intricate network of bubbles, filaments and pillars in this very rich stellar nursery.

Swiss Astronomy in 2013

2.1 The Changing Landscape

Since the writing of the Roadmap in 2007, the Swiss astrophysics Landscape has changed significantly, both nationally and internationally. In Switzerland, a number of new research groups were established; each has led, or will be leading, to the appointment of at least one new professor:

- Star and Planet Formation Group at the ETH Zürich (2009)
- High-Energy Heliophysics Group at the FHNW (2010)
- Center for Space and Habitability at the University of Bern (2011)
- Astroparticle Physics / Cosmology Group at the University of Basel (2011)
- Fundamental Cosmology Group, ETH Zürich (2011)
- High Energy Multi-messenger Astrophysics Group, University of Geneva (2011)
- NCCR PlanetS at its leading houses (Universities of Bern and Geneva in 2014)

In addition, new professors were also appointed in already existing research groups thereby strengthening local priorities in the corresponding fields of research:

- Exoplanets, University of Geneva (2007)
- Galaxies and Cosmology, University of Geneva (2008)
- Exoplanets, University of Geneva (2011)
- Stellar Physics, University of Geneva (2011)
- Computational Astrophysics, University of Zürich (2013)

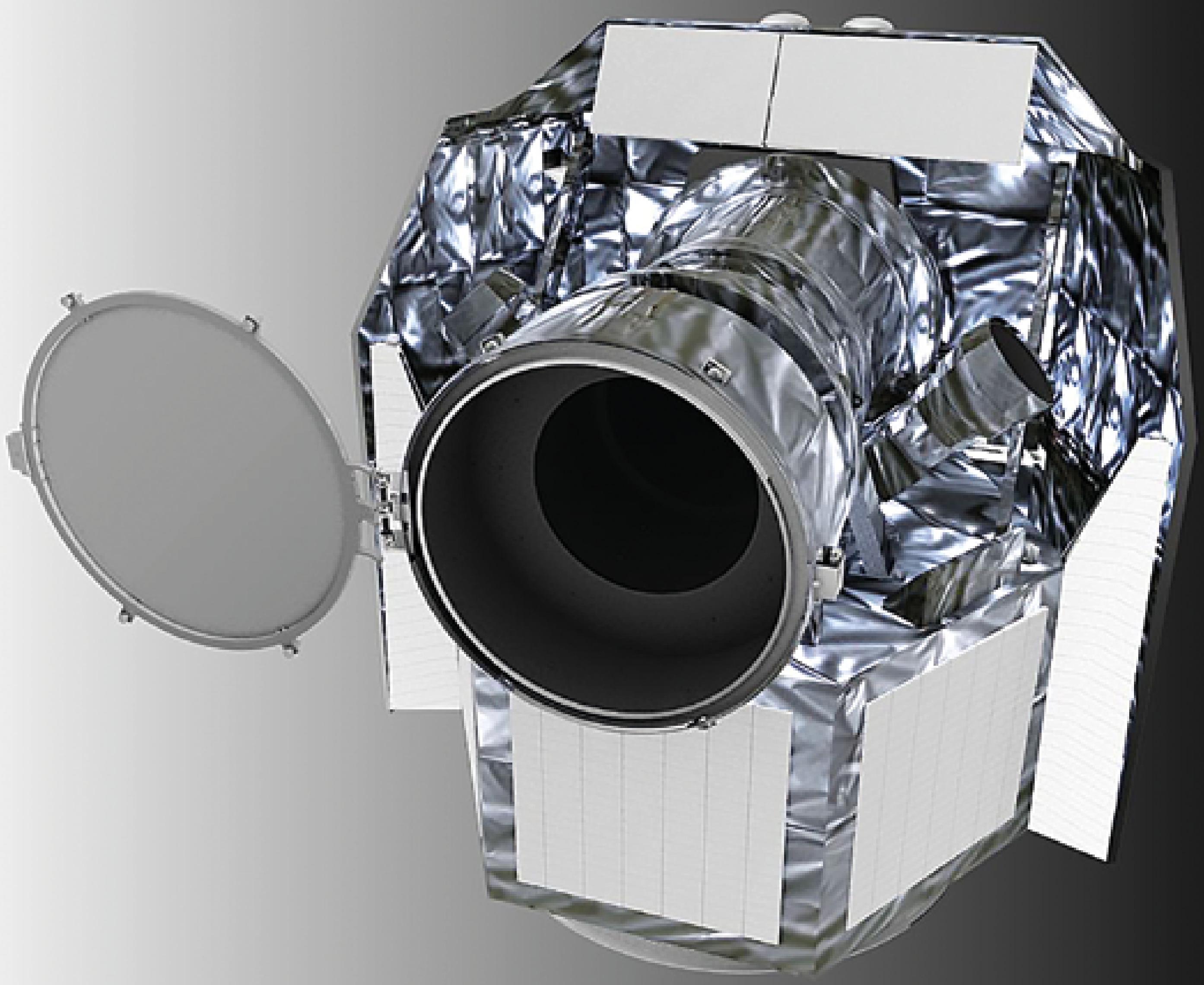
While new professors were appointed and new groups were established, others where terminated. The Institute for Astronomy at the University of Basel was closed with some of its activities being transferred to the physics department. The solar physics group at the ETHZ was dissolved with part of its activities transferred to FHNW and IRSOL. With this termination solar physics is no longer represented at a Swiss university.

On a European scale, the most important single event that will be shaping Swiss astronomy for years to come was the decision by the ESO Member States to go ahead with the project to build a 39m telescope in Chile (the European-Extremely Large Telescope, in short E-ELT) even without the formal ratification of the Brazilian accession being completed. In the 2007 Roadmap, the E-ELT was singled out as the most important priority for Swiss ground-based astronomy. The decision to proceed with the project is therefore most welcome by the Swiss astrophysics community.

Switzerland has a rich tradition of success in both ground- and space-based instrumentation. The period since the publication of the 2007 Roadmap has been particularly successful in terms of significant Swiss participation in new large projects, ground-based and space-based. This success relies on scientific leadership, technological capacities in instrument building, and appropriate funding through the FLARE (formerly FINES), PRODEX, and "National Complementing Activities" (NCA) programmes.

Following the recommendation of the 2007 Roadmap, the budgets of PRODEX and NCA have been increased. This has led to the possibility for Switzerland to become involved in the development of several space instruments and mission ground segments to an extent never possible before. Unfortunately, the funding available to finance the development of ground-based instrumentation (FLARE) did not follow the same evolution. In light of the increased complexity of the instrumentation foreseen for the E-ELT, while concurrently maintaining the VLT and its instrumentation at the forefront of modern astronomy, this lack of funding increase will lead to a critical situation in the near future. In the current international astronomical context, the active participation in the building of instruments is the only way to guarantee a significant share of the observation time, priority access to data, and hence the largest possible scientific return. This is bound to be especially true for the E-ELT.

CHEOPS is the first small mission in ESA's Science Programme and is jointly led by Switzerland. CHEOPS will target nearby bright stars that are already known to have exoplanets in orbit around them, in order to provide new insight into the characteristics of those planets.



2.2. Forward Look

Progress in astronomy is in a large part driven by the development and availability of major ground-based infrastructures and space missions. Switzerland participates in these major international projects through its membership in organisations such as ESO and ESA. These organisations provide the basis for a large part of the experimental and observational astrophysical research. Swiss astronomers make effective and high profile use of the common-user observational facilities of ESO and ESA, as well as ESA space platforms for in situ space research. While the Swiss research community has a direct influence on the direction of ESO and ESA, decisions made are ultimately based on the aspirations of all the partners throughout Europe. This means that the Swiss community must retain some flexibility to respond to the changing international context in which it operates. To achieve this, maintaining a wide range of Swiss

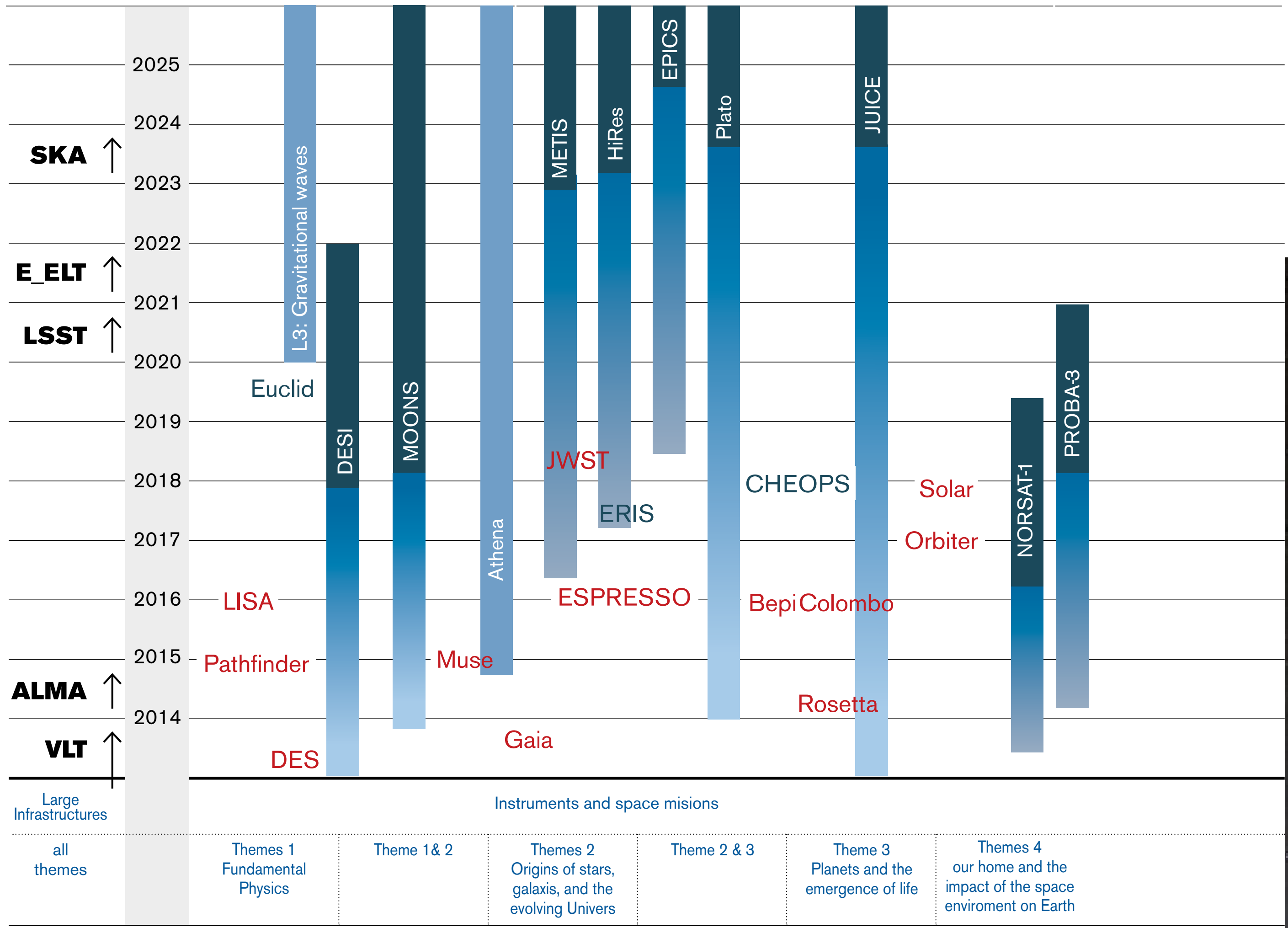
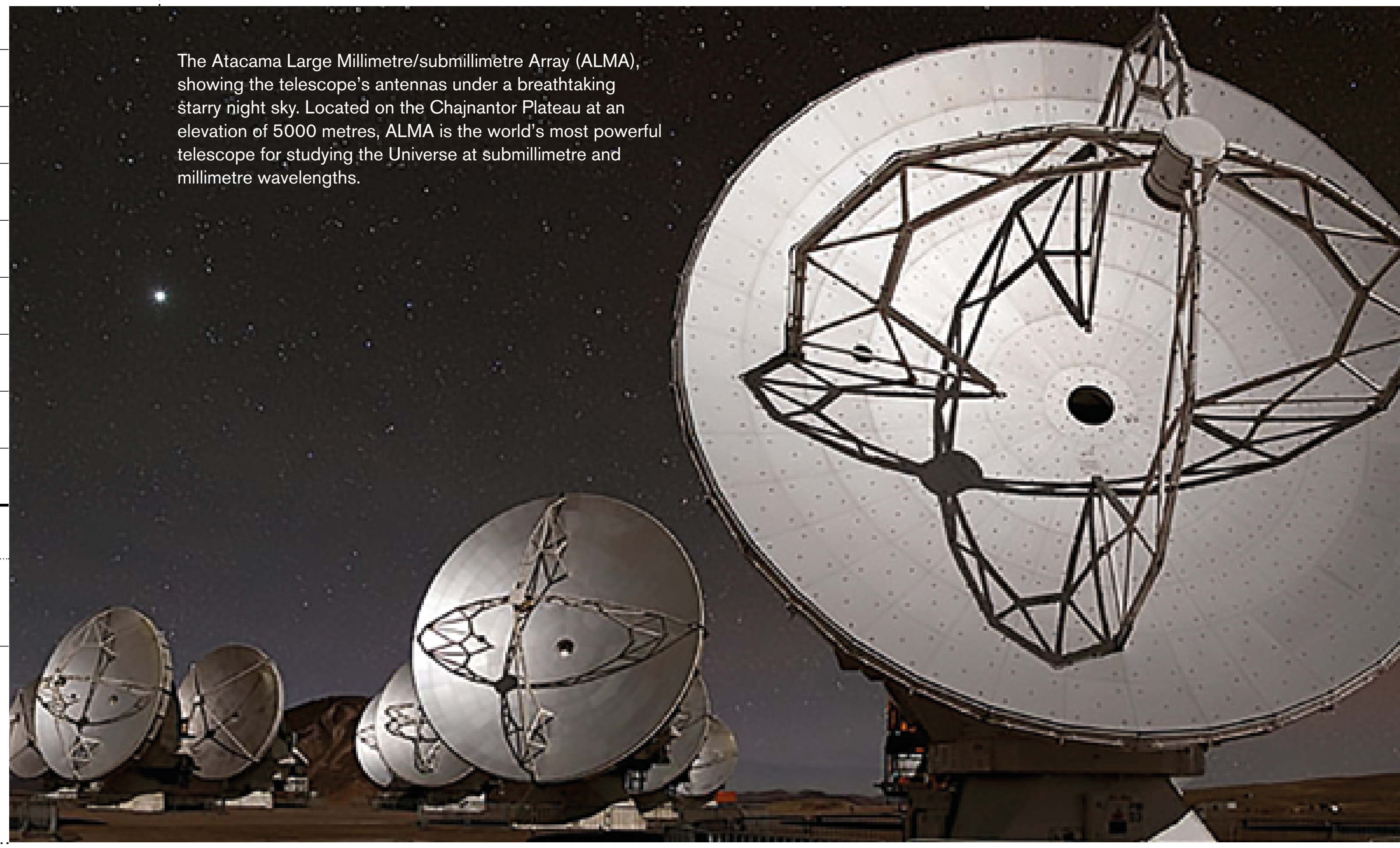


Fig. 1: On-going and future large projects within the four themes. Displayed are all activities within the boundaries of the update – with significant Swiss involvement either existing or in relatively advanced stages of planning. Projects in red are those already mentioned in the 2007 Roadmap, while those in blue are new ones. Missions or projects within the vertical bars are projects for which the funding of the Swiss contribution is only partially secured or not yet requested. In these boxes, dark colours indicate that the instrument is operating on the telescope or the mission is flying, light colours show preparation activities. Large international ground-based facilities are indicated in the left column in black.

scientific interests is helpful, to ensure that scientists working at Swiss institutions can take best advantage of the missions and facilities that are implemented by ESO and ESA. Figure 1 displays the various large projects with major Swiss involvement that are currently underway or which are planned to become operational within the next decade and for which work is already being carried out today (see Appendix 2). This figure illustrates several important aspects of modern astronomical research. In particular, the figure shows that large projects require considerable advance planning and sizeable amount of work to be carried out before participation in the mission is secured and scientific data are obtained. They represent true longterm investments in the future.

Swiss astronomers have been successful in getting involved in a significant number of large projects, and these projects are spread over all four scientific themes. While some are multi-purpose observatories (e.g. JWST, Gaia, Euclid) others are quite specialised and address specific bodies (e.g. Rosetta, BepiColombo, JUICE) or carry out specific measurements (e.g. ESPRESSO, CHEOPS, MOONS). The large number of instruments and missions with significant Swiss implications mirrors the breadth of Swiss astronomy.

While Figure 1 shows the projects that are on the horizon today, work is already being carried out to define projects and missions that are even beyond today's horizon. Such preparatory work is essential to position Swiss teams for participation in the most interesting future developments. For brevity these "still beyond the horizon" projects and missions are not discussed, but definition work takes place in all four themes.



The Atacama Large Millimetre/submillimetre Array (ALMA), showing the telescope's antennas under a breathtaking starry night sky. Located on the Chajnantor Plateau at an elevation of 5000 metres, ALMA is the world's most powerful telescope for studying the Universe at submillimetre and millimetre wavelengths.

3. Recommendations

In 2007, the "Roadmap for Swiss Astronomy" issued a set of recommendations, which defined the priorities for the period 2007-2016. The recommendations in this update take into account recent achievements and the evolution of the national and international landscape. A global strategic approach, in which the strengths of the Swiss astronomy community are considered, is essential to build on past investments, as well as focus investments to create an even brighter future. Here we issue several findings of fact and resulting recommendations for action aimed a achieving this. We close with a few additional observations.

3.1 Large international projects in general

Astronomy covers a broad area of natural sciences (see also Appendices 1 & 2). While the understanding of the formation and evolution of the Universe as a whole (including galaxies, stars, planets) represents its classical core, modern astronomy also includes aspects of chemistry, geophysics and even biology. Its diverse multi-disciplinary nature distinguishes it from other sciences in which large investments in infrastructure are also necessary (e.g. particle physics). Over the years, in order to avoid duplication of efforts, Swiss astronomy research groups have specialised, realising a diverse landscape.

Finding 1
The breadth of Swiss astronomy is impressive and has even grown since the formulation of the Roadmap for Swiss Astronomy 2007-2016. This diversity in scientific interests calls for diversity in capabilities, realised through ground- and space-based telescopes and instrumentation, as well as in theoretical and computational developments including specialised analysis tools needed to deal with very large datasets. This diversity is also an important asset within the framework of international agencies, which set priorities for major projects. Defining a single national priority is impossible without excluding a large fraction of the astronomy community and disregarding past investments.

Recommendation 1
The diversity of astronomical research in Switzerland should be preserved through the concurrent support for participation in multiple large projects having different science goals with significant Swiss participation.

The most pressing scientific questions, which are also of great public interest, require ever more sophisticated capabilities: the needed infrastructures come at a cost. The past and present investments by Switzerland in astronomical research have been remarkable. This has allowed unprecedented involvement by Swiss teams in the largest ground- and space-based projects and has led to great scientific successes for Switzerland.

Finding 2
As future projects worldwide grow in size and complexity, significant Swiss participation in those most essential will increasingly strain available funding and make prioritisation necessary.

Recommendation 2
While scientific excellence must be the ultimate criterion, projects of equal merit should be preferred if:

- *a They establish or strengthen the scientific leadership of Switzerland in an area*
- *b They address the needs of a broad community*
- *c They are being carried out within the framework of ESA and/or ESO*

3.2. Ground-based astronomical instrumentation

The availability of the VLT to ALMA, and eventually to the E-ELT, provides Swiss astronomers with access to the worlds' most powerful telescopes and state-of-the-art instruments covering a broad range of wavelengths. While the E-ELT will be used to address some of the most pressing scientific

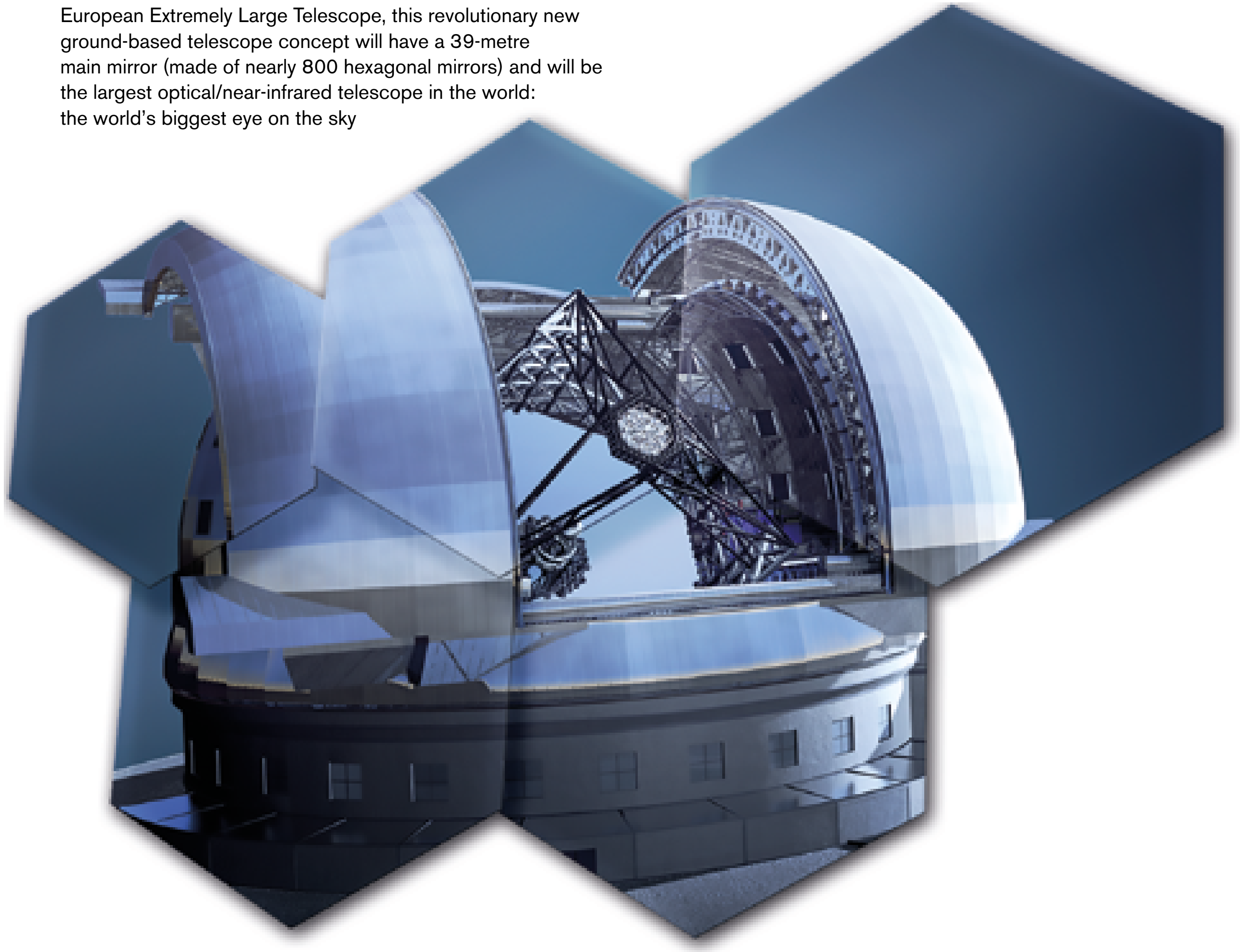
questions in astronomy, the VLT and its suite of instruments will remain the workhorse facility for most astronomers. This implies continued investment in new instruments, as well as maintaining the existing infrastructure.

Finding 3
A strong ESO remains the greatest asset for Swiss ground-based astronomy.

Recommendation 3
ALMA in full routine operation mode, a timely and successful completion of the E-ELT with a powerful suite of instruments, and the VLT remaining a world-leading observatory in the E-ELT era remain top priorities for Swiss astronomers. Within ESO, Switzerland should continue to provide strong support for these facilities.

The success of the VLT as an observatory – in terms of science output – is based on a model in which ESO and instrument-building consortia drawn from the scientific community of Member States work together to build powerful instruments. The consortia, which invest significant resources, are rewarded with large amounts of Guaranteed Time Observing (GTO) once the instrument is on the telescope. FLARE (and previously FINES) have allowed Swiss astronomers to use this approach extremely successfully in the past (e.g. HARPS and the discovery of exoplanets with masses approaching that of Earth). The new VLT instruments, with important FLARE-funded Swiss participation that have just been commissioned or will be in the near future (e.g. MUSE, SPHERE, ESPRESSO), promise similar large rewards for Switzerland.

European Extremely Large Telescope, this revolutionary new ground-based telescope concept will have a 39-metre main mirror (made of nearly 800 hexagonal mirrors) and will be the largest optical/near-infrared telescope in the world: the world's biggest eye on the sky



Finding 4
The participation by research teams in instrument building consortia enables access to significant amounts of observing time needed to maintain scientific leadership. This trend is likely to grow even more in the future, in particular with the E-ELT.

Recommendation 4
Given the size and number of instruments foreseen for the future world-leading astronomical facilities, at least a doubling of the FLARE support for astronomical instrumentation is required. Further, the rules governing FLARE should be adapted to better reflect the constraints imposed by the long-term nature of these projects.

Outside the ESO framework, there are compelling small to medium projects that do not duplicate the ESO infrastructures and represent unique and cost-effective opportunities for Swiss astronomers. In addition to instrumentation, software development, as well as contributions to capital costs granting access to data, are diverse ways in which Swiss astronomers can consolidate scientific leadership in specialised areas.

Finding 5
Some areas of astrophysical research can be best addressed through the participation in projects taking place outside the framework of ESO.

Recommendation 5
Financial support should be made available for small to medium size projects carried out beyond the traditional ESO boundaries. This support should be flexible in both its purpose and its use with the goal to extend research infrastructures to areas outside the main focus of ESO.

There are several new large international projects (including, but not limited to SKA, LSST, NOEMA) currently under development, which are likely to become major facilities in the future. For example, SKA will represent a huge leap forward in understanding the early Universe and large-scale structure formation, in relation to the formation and evolution of galaxies. With the changing landscape of Swiss astronomy, the scientific interest in SKA has grown significantly since the 2007 Roadmap. The LSST will also impact all areas of astrophysics when data become available in fifteen years.

Finding 6
At present, participation in some of the new large astronomical facilities of the future is done at the level of individual research groups or through ad hoc collaborations that benefit in a concomitant way.

Recommendation 6
A federated participation by Switzerland in some of these future large projects, guaranteeing access to all researchers working at Swiss institutions, would be beneficial. Among these additional facilities, the Swiss astronomy community considers SKA and LSST as scientifically most attractive at present. It is imperative that the cost of joining one of these new projects be covered through newly available funding and not at the expense of the active Swiss participation in ESO or ESA.

3.3 Space-based missions and experiments

Participation in the ESA Science Programme is the major way in which Swiss astronomers, solar physicists, and planetary scientists obtain access to data produced by revolutionary capabilities in space. By participating in the development of space-based instruments, they have not only a privileged access to the data but also gain a better understanding of how to best exploit them – thereby gaining a strong competitive advantage. Participation in building mission payload elements or even in leading an entire mission (CHEOPS) has been made possible by the PRODEX programme and/or the “National Complementing Activities” (NCA). In addition, PRODEX funding, by requiring a substantial (50% or more) industrial participation in projects, naturally creates close ties between academia and industry and promotes technology transfer.

Finding 7
The recent successes of Swiss scientists in proposing, and building (with the help of industry) space experiments have been such that efforts are now being funding limited.

Recommendation 7
Maintaining Swiss leadership in space sciences and technology requires an increase of 50% in PRODEX funding over the next five-year period.
Over the years, Swiss teams have also developed essential competences in other areas critical to success in space-based research, such as ground segment software. These activities, which also require long-term commitments, fit only with difficulty within the PRODEX programme. Furthermore, innovative ways to conduct novel astrophysics experiments from balloon-based platforms, sub-orbital rocket launch, and other bilateral collaborations (e.g. Russia, China) are under-exploited: their number and complexity promise to increase in the future as more space-fairing nations emerge.

Finding 8
In comparison to other countries of similar size (e.g. Belgium), Switzerland’s ability to fund activities outside the framework of ESA is severely limited. In addition, funding of auxiliary technical activities (for ESA and non-ESA missions) that are not directly related to the building of experiments (e.g. software development) is also needed.

Recommendation 8
A 50% funding increase of the “National Complementing Activities” over the next 5 years is necessary.

3.4 Additional Observations

We also offer these three additional observations, which describe important aspects of science funding in Switzerland as it relates to astrophysics. These observations should be considered in any global strategic review of national priorities for Swiss astrophysics, but do not come associated with actionable recommendations for SERI or SNSF.

Observation 1
In Switzerland, the funding for large projects is decoupled from the funding supporting their scientific exploitation through data analysis and theoretical or computational investigations. The funding for this exploitation comes in a large part through competitive project grants from SNSF. Hence, SNSF plays a central role in adding scientific value to the investments made in large projects and infrastructures.

Observation 2
In a research landscape shaped in part by large-scale projects, the availability of a permanent and highly skilled staff is essential. In Switzerland, only Universities, ETHs, and FHS can ensure the availability of such staff.

Observation 3
Full access to European programmes is necessary to remain embedded in the European astronomical research community. Furthermore, the ability to attract and eventually lead European projects has become a benchmark, by which quality and competitiveness of research in a country is evaluated.

Appendix 1: Summary of achievements since the 2007 Roadmap

Switzerland is a fertile ground for astrophysics and the research community is characterised by diversity and excellence. A healthy mix of projects carried out by individuals as well as large consortia provides the flexibility to adapt to a changing international landscape, as well as the possibility for truly novel ideas to be pursued. This mix is illustrated by this short summary of scientific achievements since the publication of the 2007 Roadmap.

1. Theme 1: Fundamental Physics

Astrophysics can be either the application of physical laws to cosmic phenomena, or the use of cosmic phenomena to extend our knowledge of physical laws. While the former is evident, the latter comes from the fact that astrophysical environments can be so extreme that physical conditions unattainable in our laboratories can be examined and new insights about the nature of the fundamental forces or laws of Nature can be gained.

Probably the most extreme example of such conditions is the Big Bang itself, and the rapid expansion of the early Universe that followed: the so-called inflation phase. During inflation, quantum fluctuations are amplified and, as the Universe expands and cools, finally result in classical density fluctuations. This is the time at which the structure of the future observable Universe is being defined and baryogenesis is being completed. Testing this phase in the laboratory would require energies 10 billion times larger than those currently reached at CERN's Large Hadron Collider (LHC).

Swiss research groups located throughout the country are developing relevant theories and means to test them with great successes. Accurate measurement of the anisotropies and polarisation of the Cosmic Microwave Background (CMB), such as those provided by the ESA Planck satellite, is the best window into the Universe at very high energies. Swiss research teams participated in the mission and are still active in the cosmological analysis and interpretation of the data. Planck currently yields the most precise determination of the age of the Universe (although with the use of priors), of the spatial curvature of the Universe, of the amount of baryons in the Universe, of the spectral index of primordial fluctuations and, together with additional astrophysical data, the current best constraints on the mass of the neutrinos.

In 2011, the Nobel Prize in physics was attributed for the discovery of dark energy resulting in an accelerated expansion of the Universe. Addressing the question of its nature requires wide-field galaxy surveys carried out from the ground and from space. Swiss teams are heavily involved in current and upcoming ground-based experiments, such such as DES, BOSS, DESI and LSST. Switzerland is also deeply involved in the ESA Euclid mission. Euclid will observe 15000 square degrees, in visible and near-infrared wavelengths. Several Swiss institutes are directly involved in the preparation of the mission through essential activities related to theory, observations, simulations, data reduction, and hardware.

The bulk of the mass of our galaxy is in the form of dark matter. The identification of the nature of dark matter is one of the main challenges of modern physics. Astronomical observations in the X-ray and gamma-ray domain, and with neutrinos, are our few chances for such an identification (along with the complementary direct detection searches and particle collider experiments). Over the last years X-ray and gamma-ray telescopes have started to search for the signal from interactions of dark matter particles (decay and/or annihilations) in the halo of the Milky Way, from the galactic centre and other nearby structures. Swiss researchers are successfully contributing to this on-going search, which results in significant tightening of bounds on parameters of particle models of dark matter.

2. Theme 2: Origins – stars, galaxies and the evolving Universe

We live in a Universe that changes with time as structures form and evolve. Stars are the building blocks of the visible Universe. Over the history of the Universe, they have produced most of the chemical elements, and released them in winds or powerful explosions. Their newly synthesised and often radioactive elements imprint in the interstellar medium the detailed traces of stellar evolution and provide a natural clock to mark the passage of time. Since 2007, Swiss astronomers have exploited with great success world-class ground- and space-based observatories, and fundamental theoretical breakthroughs were obtained thanks to the development of sophisticated models of the sun, stars, and stellar explosions that probe stars as high-energy laboratories of physical processes. This led to a number of major contributions both observational and theoretical in a wide range of topics in stellar evolution (including the sun) as well as in the dynamical and chemical evolution of the Universe at all scales. Among the many highlights in this domain we can quote the challenging numerical simulations incorporating complex magneto-hydrodynamical processes that have finally led to successful supernova explosions, and the spinstar model proposed for the first stars in the Universe, which opened new views on how these element factories enriched, and helped ionise sub-structures in the early Universe. Following the recommendation of the Roadmap, a national school in astrophysics entitled "Stars and Supernovae" was organised within the Stellar Evolution Network and held in 2012.

Since its launch in 2002, the ESA satellite mission INTEGRAL has played an important role in the development of high-energy astrophysics in Switzerland. Together with the other currently available X-ray observatories, especially XMM-Newton, they have led to considerable progress in our understanding of neutron star and black hole powered phenomena such as pulsars, supernovae remnants, gamma-ray burst as well as of X-ray binaries, active galactic nuclei, and galaxy clusters. The outstanding success of the current generation of X-ray observatories has transformed X-ray astronomy into an essential tool for the understanding of fundamental questions, such as the physics of matter at extreme densities via the determination of pulsar/neutron star radii, general relativistic effects in the vicinity of black holes, accretion and jet formation, the role of feedback from supermassive black holes in the evolution of galaxies and galaxy clusters, as well as the build-up of the largest cosmological structures and the re-ionisation of the Universe.

Swiss research in galaxy formation and evolution has continued at the forefront of the field. Combining the deepest ground-based (VLT+) and Hubble Space Telescope observations, Swiss astronomers have successfully participated in searches for the most distant galaxies in the Universe and led discoveries about their physical nature. This has provided a unique view on the first objects formed shortly after the Big Bang, at the end of the dark ages and well within the era of cosmic re-ionisation. The MUSE instrument on the ESO VLT, which has seen first-light at the beginning of 2014, will be a unique facility in the next decade to study the galaxy populations emerging from the re-ionisation epoch. Another major step forward for Swiss astronomers will come with MOONS, the next generation multi-object infrared spectrograph on the VLT. MOONS will enter operation in 2018 and will survey the galaxy population at a look-back time of over 10 billion years with the same level of precision that today can be achieved in nearby galaxies. Further ahead, upcoming facilities such as the JWST, E-ELT, and SKA are expected to revolutionise our knowledge of the very early phases of galaxy formation.

Switzerland also plays a major role in the Gaia mission, which was launched in 2013, and which will map the entire Milky Way galaxy. Swiss astronomers were selected to lead the "Variability" Coordination Unit (managing and coordination of 18 European institutes) within the Gaia Data Processing and Analysing Consortium of the Gaia mission. This coordination effort will provide a valuable database for studying time-dependent phenomena in all phases of stellar evolution.

The exchange of gas between galaxies and their surroundings is central to their evolution: infalling material fuels star formation, while energy injection from massive stars and supernovae may regulate further star formation. Enriched material has been seen in absorption for many years in the intergalactic medium at high redshifts. Recent work in Switzerland has now established an unambiguous connection between this material and bipolar winds driven by the intense energy injection associated with supernovae in vigorously star-forming galaxies in the early Universe. Furthermore, a quite different line of research has established that these winds are highly magnetized, potentially providing an explanation for the presence of significant fields in intergalactic space and, by removing small-scale magnetic turbulence, resolving difficulties in the operation of galactic-scale dynamos.

A complementary evidence for the existence of magnetic fields in intergalactic space, spread by the galactic winds or left from the earlier epochs of evolution of the Universe, was found via observations with gamma-ray telescopes. Very high-energy gamma-rays propagating from extragalactic sources initiate electromagnetic cascades in intergalactic space. The details of the gamma-ray signal from such cascades are sensitive to the magnetic field. Swiss researchers have used this effect to establish the presence of magnetic fields in the voids of the Large Scale structure.

While the theory tracing the development of dark matter structures is now well mastered, the evolution of gas and stars is not easily linked to the evolution of non-baryonic matter. The processes of gas accretion, heating, cooling, and star formation are still poorly understood from both theoretical and observational points of view. Star formation occurs in massive, dense and cold gravitationally bound giant molecular clouds, but we do not know

Picture taken with ESO's Very Large Telescope shows the galaxy NGC 1187. This impressive spiral lies about 60 million light-years away in the constellation of Eridanus (The River). NGC 1187 has hosted two supernova explosions during the last thirty years, the latest one in 2007

how star formation proceeds on a galactic scale. Work continues to understand the dependence of outcomes of star formation in local environments (e.g. initial mass function, multiplicity, companion mass ratio distributions, boundedness of star clusters, feedback, lifetime of molecular clouds and the duration of star formation, star formation efficiency) on initial conditions and how to relate these to galactic scale star formation. These topics are also addressed by searching for the remnants of ultra-faint galaxies, by studying the chemical abundance patterns of the earliest generations of stars in the Local Group dwarf spheroidal galaxies, and by numerical simulations of the tidal interactions of these galaxies with the Milky Way.

Swiss astronomers have also carried out large galaxy surveys collecting a vast amount of data on the population of galaxies and active galactic nuclei at low and high redshifts, and on their environment. A real breakthrough has come from the development of new phenomenological approaches to understanding the evolving galaxy population. These have been based on identifying simplicities of the galaxy population and exploring the implications of these via the most basic continuity equations. Paradoxically, by stepping back from physical preconceptions about how galaxies should be evolving, a much clearer picture has emerged of how they actually are behaving, in terms of both the fuelling of galaxies and the quenching of their star-formation activity.

Star formation activity of all the galaxies in the course of their evolution leads to accumulation of diffuse infrared and visible light, collectively known as Extragalactic Background Light, EBL. Direct measurements of such light are not possible because of the high level of zodiacal emission in the visible and infrared. However, the spectrum of EBL is measured indirectly by gamma-ray telescopes, via the effect of absorption of the highest energy gamma-rays in interaction with the EBL photons. Swiss astronomers use the newly available gamma-ray techniques of the measurement of EBL for the study of evolution of the star formation activity of galaxies.

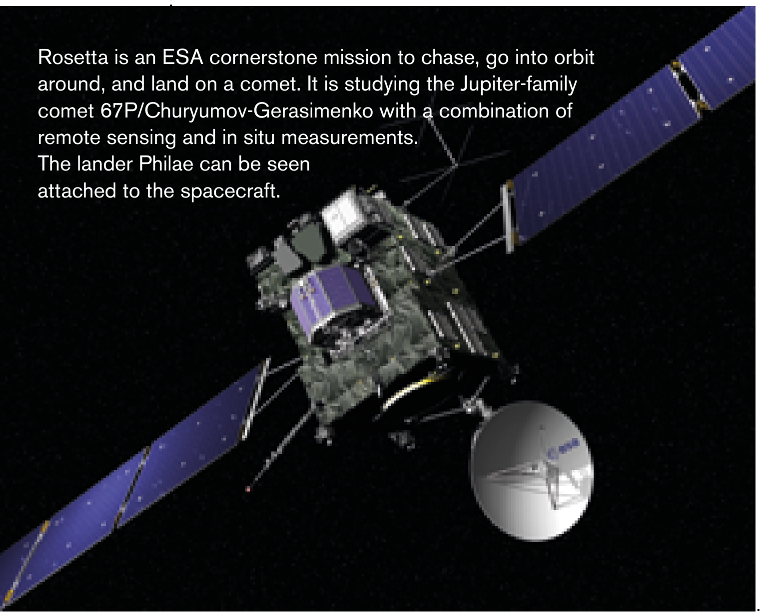
Computer simulations play a key role in modern science, using virtual data as a link between our theoretical understanding of the Universe and our observations of the physical world. They are also used to construct mock Universes to test new theories and open new avenues of research. In cosmology, simulations have an even greater impact because we have an excellent understanding of the initial conditions of our Universe through the observations of the CMB. For example, next generation galaxy surveys such as Euclid will be able to measure the cosmological power spectrum up to k=10 h/Mpc, and the key cosmological parameters to percent level precision. As a consequence, to model this regime we will have to better understand the physics of baryonic matter, which boils down to understanding star formation, galaxy formation, feedback processes and their impact on the distribution of matter on small-scales. Hydrodynamical simulations designed to model these processes are planned by the Euclid consortium in order to generate correction terms that can be added to the standard pure N-body codes. Some of the few codes capable of scaling successfully to tens of thousands of cores and performing the target resolution for full Euclid simulations have been developed in Switzerland.

3. Theme 3: Planets and the emergence of life

The scientific exploration of the solar system represents the only opportunity for carrying out detailed in situ measurements of celestial bodies beyond our Earth. Within the original Roadmap, the in situ exploration of Mars (Mars Express, MRO and ExoMars), of Venus (Venus Express), of comets (Rosetta), and of Mercury (BepiColombo) were mentioned as important elements of the scientific and exploration programmes of two major Agencies (ESA and NASA), in which a significant Swiss participation was taking place.

The HiRISE imaging system on MRO has identified what are almost certainly traces of extant liquid water on Mars. Through laboratory investigations, Switzerland has supported what is probably one the most significant findings in the field of planetary habitability in the past three years[1]. Switzerland is now involved in the building of part of the imaging system for the ExoMars Trace Gas Orbiter. Rosetta, ESA's "comet chaser", was woken, in early 2014 for the Rendez-vous with the comet and provided startling pictures. After a decade of waiting for this event, Swiss scientists are gearing up for a whole year of measurements, as the satellite will follow the comet on its orbit. Switzerland has the responsibility for a suite of instruments (ROSINA) dedicated to chemical composition measurements of gases, and participates strongly in the imaging system (OSIRIS). As the launch of the Mercury mission BepiColombo is nearing (2016), the instrumentation for the laser altimeter project, BELA, which is designed to measure the surface topography and participate in the planetary geophysics experiment, is getting close to completion. The spacecraft is expected to reach Mercury after a cruise phase of 6 years. ESA's JUICE mission was recently selected for implementation to study Jupiter and its icy moons in detail.

This year the count of confirmed extra-solar planets has exceeded 1500. As the field has matured in the past 19 years since the pioneering discoveries led by M. Mayor at the Astronomy Department of the University of Geneva, the scientific focus has shifted from discovery to characterisation of these other worlds. We can now assess the temperatures, luminosities, and compositions of a handful of planets whose light is detected directly through secondary eclipse or resolved imaging, in addition to dozens of worlds whose bulk composition is constrained through estimates of their masses (radial velocity) and radii (transit).



Rosetta is an ESA cornerstone mission to chase, go into orbit around, and land on a comet. It is studying the Jupiter-family comet 67P/Churyumov-Gerasimenko with a combination of remote sensing and in situ measurements. The lander Philae can be seen attached to the spacecraft.

Exoplanet research in Switzerland remains internationally leading and, following the recommendation of the 2007 Roadmap, has been increasing coordination to achieve a whole, which is greater than the sum of the parts. Collaborations such as HARPS and SPHERE, already in place at the writing of the Roadmap, remain strong and successful. HARPS continues to lead the world in radial velocity exoplanet discoveries including bodies with minimum masses close to that of the Earth. SPHERE achieved first light in May and will become one of the premiere facilities for imaging planets in the next decade. ESPRESSO, the next generation of high-precision spectrographs under Swiss leadership, to be installed at the VLT in 2016, will complement the palette of instruments in the hand of Swiss astronomers, allowing for the detection of exoplanets as small as the Earth and measurement of their mass.

CHEOPS, the first Swiss scientific satellite, was selected in October 2012 as the first S-class mission in ESA's Science Programme. CHEOPS is the first mission dedicated to search for transits of exoplanets by means of ultra-high precision photometry on bright stars already known to host planets. It will provide the unique capability of determining accurate radii for a subset of those planets for which the mass has already been estimated from ground-based spectroscopic surveys. It will also provide precise radii for new planets discovered by the next generation of ground- or space-based transit surveys (Neptune-size). By unveiling transiting exoplanets with high potential for in-depth characterisation, CHEOPS will also provide prime targets for future instruments suited to the spectroscopic characterisation of exoplanet atmospheres (e.g. JWST). CHEOPS, which was made possible by the significant funding increase of the PRODEX and ANC programmes following the 2007 Roadmap, will extend Switzerland's dominant position in the field.

Finally, the selection of the NCCR PlanetS, started on 1 June 2014, marks the beginning of a new era in the studies of the formation, evolution, and characterisations of planets inside and outside the solar system. From individual research group efforts and ad hoc collaborations already strongly encouraged in the 2007 Roadmap, the field will now be moving towards a coordinated, coherent and multi-disciplinary national research programme.

4. Theme 4: Our home and the impact of the space environment on Earth

Space geodetic techniques such as Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Global Navigation Satellite Systems (GNSS), and Doppler Orbitographie et Radio-positionnement Intégrés par Satellite (DORIS), provide the metrological basis for the establishment of the global terrestrial reference frame, for the determination of the transformation parameters between the terrestrial and the celestial reference frame, and for a multitude of studies related to the system Earth – our "cosmic home".

The International Association of Geodesy (IAG) founded the International GNSS Service (IGS) in 1994 to support the development of GNSS data analysis, and to exploit the scientific use of GNSS. The Center for Orbit Determination in Europe (CODE), which is led by Switzerland, is one of the leading global analysis centres of the IGS.

Earth's bounded observations play an important role in better understanding the sun, and Swiss solar physicists are performing polarimetric observations, using the most sensitive polarimeter (ZIMPOL), in order to better understand the sun's magnetic field. Observations are also carried out at GREGOR, the largest such facility currently operating.

In their latest report on "Climate Change, impacts and vulnerability in Europe 2012", the European Environment Agency stated the expected severe impacts in Europe due to climate change (EEA, 2012). One of the driving factors is ice melt, e.g. the Greenland ice sheet, and the changing hydrology within Europe. Time variability, as derived from space borne gravity field missions, is one of the most reliable ways of obtaining such evidence. This approach is closely related to satellite orbital dynamics. With their long-standing expertise in these problems, Swiss institutes have made major contributions to this field.

The proliferation of space debris and the increased probability of collisions and interference raise concerns about the long-term sustainability of space activities, particularly in the low-Earth orbit and geostationary orbit environments. International organisations at different levels are examining measures to enhance the long-term sustainability of such activities, among them the UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS),and the Inter-Agency Space Debris Coordination Committee (IADC). Swiss researchers participate in the development of efficient and cost-effective measures to reduce the creation and proliferation of space debris by studying the current debris population, to identify their major sources and release mechanism.

Our society has become more and more dependent, directly or indirectly, on satellite services. These are vulnerable to what is called "space weather", which is the impact of solar events, or more generally speaking, events from outer space, on the Earth. The world-wide community is putting into place warning centres, and the United Nations Committee on the Peaceful Uses of Outer Space has a working group active on the subject. Swiss scientists are actively involved in research for understanding the solar processes, as well as assessing the potential impact on Earth.

[1] see http://www.tagesschau.sf.tv/Nachrichten/Archiv/2011/08/04/Vermischtes/Nasa-Ziemlich-sicher-Wasser-auf-dem-Mars

Appendix 2: Summary of near and mid-term perspectives

Many projects in astronomy require prior major investment in large infrastructures, or rely on a particular space mission. Both require significant lead time and planning. Furthermore, the future availability of a particular type of data generally triggers preparatory work including theory or numerical simulations. Hence, a clear picture of the major future developments is essential for successful investments. In the following, we provide a brief look forwards to the four major science themes.

1. Theme 1: Fundamental Physics

The nature of dark matter, dark energy, inflation and gravity poses some of the most pressing questions in fundamental physics and cosmology today. To shed light on these questions, astronomers in Switzerland will build upon their current projects to ensure a leading role in key international experiments and theoretical projects in the medium term. In particular, the following describes how they will pursue cosmological studies of the Cosmic Microwave Background (CMB) and wide-field Large-Scale Structure (LSS) surveys, as well as astrophysical experiments relevant to fundamental physics.

The Cosmic Microwave Background

The CMB provides a high-precision picture of the early Universe and its observations provide some of the strongest constraints on the standard cosmological model. The ESA Planck mission was launched in 2009 and astrophysicists from Switzerland, as members of its core team, have participated in the first data and science release in 2013. These data have delivered the most precise confirmation of the standard cosmological model, but they also suggest tensions with other probes, and intriguing anomalies that require further investigation.

The team is currently extending its data analysis to the full mission, including also polarisation information. These updates will significantly tighten the constraints on the cosmological standard model and further advance our knowledge of the composition of the Universe, as well as improve our understanding of what happened just fractions of a second after the Big Bang.

In addition, Swiss astronomers are involved in theoretical investigations of this early phase of the Universe. In particular, they have developed models of inflation at the interface with particle physics. The predictions of such models are consistent with the current cosmological observations, including the latest CMB results from Planck. Inflation also sets the initial conditions for the later evolution of the Universe, and probing its nature through polarisation measurements will be a key legacy of Planck.

Large-Scale Structure Surveys

The information of the early Universe provided by the CMB needs to be complemented by measurements of large-scale structures in the low-redshift ($z < 2$) Universe. This is not only necessary to break degeneracies present when only CMB data are available, but is also essential to probe the dark matter, dark energy, inflation and gravity dominated era. These measurements can be obtained through wide-field imaging and spectroscopy in the visible and NIR, as well as radio surveys. These surveys enable several cosmological probes such as baryonic acoustic oscillations, weak lensing, redshift space distortions and galaxy clusters. These probes can then be combined to further break degeneracies and to control systematic effects.

Swiss astrophysicists will continue to play a leading role in large-scale surveys. Several of them have recently become full members of the Dark Energy Survey (DES) experiment (first light in 2012), which will run for a period of 5 years on the 4-m Blanco Telescope at Cerro Tololo Chile. DES will provide a unique imaging survey of 5000 square degrees in five visible bands, and is optimised for weak lensing. They are also involved in the Baryonic Oscillations Spectroscopy Survey (BOSS) and lead its extension eBOSS. They have also initiated and lead the COSMOGRAIL project, the COSmological MOnitoring of GRAvItational Lenses. Started in 2005, this long-term photometric monitoring (mainly from the Euler Swiss telescope at ESO La Silla) of most gravitationally lensed quasars, delivers the most precise time delays to infer an independent Hubble constant value.

Swiss scientists will also continue to work on the development of future wide field survey experiments. The Dark Energy Spectroscopic Instrument (DESI) will be a powerful multi-object spectrograph, measuring the positions and redshifts of tens of millions of galaxies. This survey, in which astronomers in Switzerland are active, will be conducted from the 4-m Mayall telescope at Kitt Peak over a five-year period (2018-2022). There is also Swiss involvement in the development of cosmological radio experiments such as BINGO, designed to perform a 2000 square degree survey in the frequency band 960 – 1260 MHz optimised to measure BAOs.

Switzerland will also continue to participate in the development of experiments for the longer term. Several institutions are involved in the preparation of Euclid, through diverse responsibilities and the hosting of one of the Science Data Centers. The acquisition of observational data by Euclid will occur during the period 2020 – 2026. Participation by several groups in the Large Synoptic Survey Telescope (LSST) will also ensure that some access to the ultimate ground-based data set in its depth and area coverage will be possible for Swiss astronomers when it starts operations in 2020. Finally, the Square Kilometre Array (SKA) will provide unique contributions to constrain the non-Gaussianity of the initial conditions for large scale structure growth and aspects of dark energy.

Tests of Gravity and Gravitational Waves

General Relativity (GR) is a very successful theory, but it has not yet been tested at very large scales and in the strong field regime. Deviations from its predictions could be related to dark matter or to dark energy.

Switzerland is involved in the construction of the LISA-Pathfinder satellite (to be launched in 2015), with the aim to test the technical feasibility of a gravitational wave detection mission. The scope of such a mission will be to detect and study low-frequency gravitational radiation. It will open new possibilities for astrophysical studies, for instance by allowing the detection of massive black holes merging at cosmological distances. Given the selection in 2013 of “the gravitational Universe” as the theme for the L3 mission (to be launched in 2034) it is likely that, if LISA-Pathfinder is successful, ESA will issue a call for such a gravitational wave mission. Therefore, this project will extend well beyond the current horizon of this Roadmap update. From the ground, the SKA will allow unique tests of general relativity and gravity waves from pulsar and black hole measurements. On the theory side, Swiss groups are active in the prediction of gravitational wave emission from compact object mergers (neutron star mergers, neutron star – black hole) as well as multi-dimensional core collapse supernova simulations. It is expected that these predictions can be tested with advanced versions of LIGO and VIRGO, sensitive in the kHz regime.

The Search for Dark Matter

Search for the nature and origin of the dark matter is one of the main foci of modern physics and astronomy research. Swiss researchers are strongly involved in this search, with theoretical groups exploring possible particle models of the dark matter, experimental physics groups performing the “direct” laboratory searches of WIMP type dark matter, and astronomy groups pursuing “indirect” searches of the X-ray and/or gamma-ray signal from interactions of dark matter particles in the halo of the Milky Way galaxy and in the nearby galaxies and galaxy clusters.

While formally outside the boundaries of this update, it is worth mentioning that a major facility for the indirect search of WIMP particles with masses in the range between tens of giga-electronvolt (ten times larger than proton mass) up to ten tera-electronvolt will be CTA. Research groups in Switzerland have become involved in the development of CTA hardware, in particular in the design and construction of an array of “small size” (4 m dish diameter) telescopes.

2. Theme 2: Origins – stars, galaxies and the evolving Universe

Astronomers working at Swiss institutions will continue leadership in studying key aspects of galaxy formation and evolution, as well as concomitant evolution of large-scale structures. The ESO VLT will remain a primary resource. MUSE, a major second-generation instrument, has been recently commissioned. This revolutionary wide-field integral-field spectrograph will enable unique studies of the relation between galactic structure, mass, dynamics and star-formation history in galaxies across a broad swathe of cosmic time. MUSE will yield extremely rich data sets on nearby galaxies, yielding new clues as to their evolutionary past, and also enable resolved studies of galaxies seen during the major epoch of galaxy formation, at redshifts $0.5 < z < 2.0$, when the Universe was forming stars ten times faster than at present. It will also enable ground-breaking studies of the evolution of the cosmic web, tracing the infall of gas onto galaxies, and study the growth of black holes as part of the formation and evolution of galaxies. Astronomers in Switzerland will have priority through guaranteed time, as well as access through open time proposals. The upgrade of SINFONI for use with new adaptive optics facility (ERIS) will provide complementary IR spectra of individual galaxies at high redshift to study gas infall and star formation. Use of ALMA (as well as the facilities of IRAM/PdB) in tandem with these optical/IR facilities will enable detailed study of galaxy formation and evolution, an area of excellence for Switzerland. Astronomers working at Swiss institutions are also poised to play a strong role in developing a high-energy astrophysics (X-ray) mission as part of the L2 theme selection recently undertaken by ESA. This facility will play a major role in understanding the co-evolution of galaxies and black holes in the next decade. Switzerland is also well positioned to take advantage of JWST when it launches in 2018, as several Swiss astronomers have access to GTO data, in particular through the Swiss contribution to the European MIRI consortium.

It is worth mentioning that in addition to its main scientific aim, related to the investigation of the nature of dark energy and the large-scale distribution of dark matter, the ESA satellite Euclid will also generate enormous amounts of data directly related to the formation and evolution of galaxies. Astronomers of nearly all fields of astrophysics will benefit directly from this unique and outstanding legacy survey.

Because most of the baryonic component of the Universe is locked up in hot gas at temperatures of millions of degrees, and because of the extreme energetics of the processes close to the event horizon of black holes, high-energy astrophysics is essential for our understanding of this hot and energetic component of the Universe. ATHENA is an X-ray Observatory combining high spatial spectroscopic resolution with deep, wide-field imaging, which has recently been selected by ESA as its L2 mission to be launched in 2028. With its long-standing tradition in high-energy astrophysics, Switzerland is clearly interested in this mission, and will participate actively in both the instrumentation and the scientific exploitation of the data.

Understanding stellar endpoints, their ejecta and the transition (as a function of initial mass) from core collapse supernovae to hypernovae / gamma-ray bursts (accompanied by black hole rather than neutron star formation), is of essential importance for the evolution of galaxies and the abundances of heavy elements. Theoretical simulations rely on fundamental physics, like the equation of state of ultra-dense matter, neutrino properties, general relativity and multi-dimensional magneto-hydrodynamics. Swiss researchers are actively involved in solving the remaining puzzles in collaboration with the European Cost Action NewCompStar, PASC (the Platform for Advanced Scientific Computing), and within the ERC project FISH.

Asteroseismology is becoming a key observational technique for future progress in stellar astrophysics. Based on the experience acquired within the CoRoT and KEPLER space missions, Swiss astronomers have started developing innovative theoretical stellar models. These will provide essential information useful for the understanding of a variety of processes, ranging from the star-

The Very Large Telescope array (VLT), located at 2600m altitude in the Atacama desert region of Chile, is the flagship facility for European ground-based astronomy at the beginning of the third millennium. It is the world's most advanced optical instrument, consisting of four Unit Telescopes with main mirrors 8.2 metres in diameter and four movable 1.8-metre Auxiliary Telescopes.

planet connection to the star formation history in the Milky Way. Finally, these models will provide the central framework for the stellar astrophysics to be carried out by the PLATO mission.

Key advances are also expected of galactic structure and many aspects of stellar structure and evolution through Swiss participation in Gaia. This precision astrometry mission (the only since HIPPARCOS thus-far, and only one planned) will revolutionise many branches of astronomy, and full exploitation of this unique capability should be a priority. Swiss astronomers planned to capitalise on our investment in building the variability catalogue to study important phases of stellar evolution (the earliest and latest), as well as asteroseismology to understand stellar structure and evolution. The latter underpins most of modern astrophysics, and is a foundation from which all of us build. Gaia will also be a powerful tool to study stellar dynamics, which will help constrain the dark matter distribution in our Milky Way, as well as dissect nearby stellar groups and clusters; key agents to explore evolutionary processes.

As modern astrophysics requires a multi-wavelength approach, expertise in infrared and millimetre-wave techniques has become increasingly important. Further, the scientific need to connect studies of galaxy formation to our understanding of stars, as well as stars to planets, makes studies of the origins of stars crucial in the current landscape. Access to optical and IR facilities such as the VLT, and soon JWST, will enable Swiss astronomers to remain at the forefront of this rapidly developing area. MOONS, the third generation infrared spectrograph being built for the VLT with Swiss participation, will carry out very large surveys of the distant Universe that can be directly compared with large surveys of the nearby Universe. Complementary studies with ALMA – and other millimeter and far-infrared facilities – will furthermore enable to connect the initial conditions of star formation with the outcomes (number of stars as a function of mass, properties of multiple systems etc.). From space, we can build on past ESA IR mission successes (e.g. ISO and Herschel) to plan for the future with instruments like SPICA. Finally, the SKA, which will open unprecedented views on the deep Universe in the radio domain, will undoubtedly play a major role in this field in the future.

3. Theme 3: Planets and the emergence of life

Exoplanets

The explosive pace of progress in exoplanet research will continue for the next several years. HARPS, HARPS-North, and Espresso will continue to push towards detection of true Earth analogues with the radial velocity technique. NGTS and other ground-based transit surveys will reveal hundreds of new worlds ready for follow-up with the VLT, as well as CHEOPS and JWST. New high contrast imaging facilities such as SPHERE and ERIS will reveal young planetary systems at large orbital radii that can confront formation theory head-on. Ultimately, PLATO, to be launched in 2024, will provide an extensive census of planets orbiting bright stars, including some on orbits comparable to the one of the Earth. Progress in understanding key physical and chemical properties will continue with an eye towards understanding whether planetary systems like our own, and the potential for habitability that they represent, are common or rare in our Universe. Switzerland is poised for leadership in all relevant domains: developing novel instrumentation, theoretical modelling, detection and characterisation of planetary systems, exploiting synergies with colleagues in Earth Science and related disciplines. A key aspect of Swiss leadership in the next decade will be to provide adequate funding for exoplanet scientists in Switzerland to play key roles in instrumentation for the E-ELT, as well as continued support for involvement in the next generation of exoplanet space missions (the ESA Cosmic Vision Programme and beyond).

While research on exoplanets demonstrates the diversity of planetary systems, the solar system provides the unique opportunity to study its constituents in exquisite detail. The necessity of putting both research fields together has become increasingly evident in recent years. In fact, the main NCCR PlanetS challenge in future years will be to bring together, in a coherent way, all Swiss research teams involved in planetary studies, regardless of the techniques (laboratory-based, observational, or theoretical) or objects they study (solar system bodies, proto-planetary discs, exoplanets).

The solar system

The JUpiter ICy moons Explorer (JUICE) mission to the icy moons of Jupiter belongs to the largest class of missions ESA can fly. As such, it is truly one of the flagship missions of the agency. It is therefore very encouraging that Swiss scientists are members of several instruments consortia for this mission. In one case, they are even co-leading the full instrument (Particle Environment Package or PEP). The mission will be launched in 2022 and will reach Jupiter in 2030. It will perform detailed investigations of Jupiter and its system in all their inter-relations and complexity, with particular emphasis on Ganymede as a planetary body and potential habitat. Investigations of Europa and Callisto will complete a comparative picture of the Galilean moons.

The scientific and technical expertise of Swiss researchers involved in the exploration of the solar system lies in remote sensing and in-situ measurements. At present, beyond ESA's JUICE mission, future opportunities can be found in the programme of other agencies. In particular NASA plans several missions to the Jupiter system, which can be considered as complementary to JUICE. They are devoted to the study of Io's volcanoes and the mapping of Europa's surface. Mars remains a main target of interest with the potential presence of liquid water, and the possibility of the existence of past and/or present life being the main scientific driver. Missions taking the form of a lander and an orbiter are currently being discussed with great interest by Swiss teams for a potential participation.

4. Theme 4: Our home and the impact of the space environment on Earth

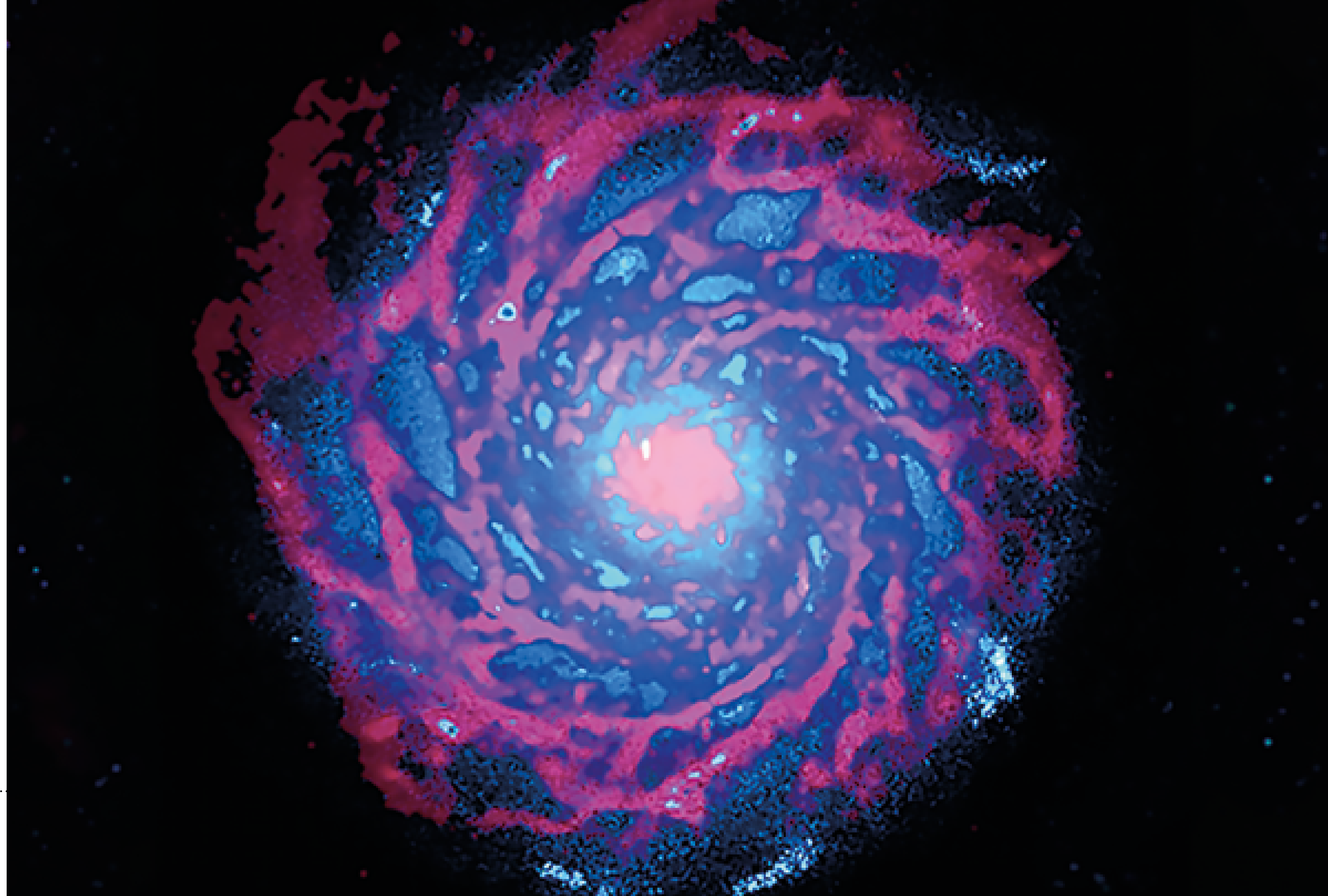
Precise geolocation of satellites in the near-Earth space, but also anywhere within the solar system is an essential capability for future space missions. So far the CODE efforts have focused on developing ultra-precise software for tracking satellites on Low Earth Orbits. The next decade will focus on extending these capabilities to interplanetary spacecraft and planetary orbiters.

A better understanding of the space debris population in the near Earth environment in terms of spatial density, of statistical orbital characteristics, as well as characteristics of individual objects will remain in the centre of interest. Extending the catalogue of known objects and determining their characteristics, developing statistical environment models, and the long term monitoring of the environment are necessary for the scientific foundation for a sustainable use of the near-Earth space.

Assessment of the activity of the sun for an efficient "now-cast" of the potential impact of space weather requires monitoring satellites. Switzerland is involved in several planned missions, as well as those in development, of which two are projects that are presently in the construction phase: NORSAT-1 and PROBA-3. A big step to understanding our sun will be ESA's Solar Orbiter mission, which will be launched in 2017, in which two Swiss institutes will be actively involved in the research teams.

5. Numerical simulations

Computer simulations play a key role in modern science, using virtual data as a link between our theoretical understanding of the Universe and our observations of the physical world. A large user community uses these codes to study galaxy formation, star and planet formation and evolution, and magneto-hydrodynamic processes in broad astrophysical regimes. The next generation of supercomputers planned at Swiss and European centres will allow a new regime of problems to be tackled. As supercomputing centres plan for exascale hardware, much work is needed to achieve the required software scaling, fault tolerance, on the fly analysis etc. Many of these core activities are coordinated under PASC, the Platform for Advanced Scientific Computing. This covers a wide range of disciplines funded by the Swiss University Conference and the Council of Federal Institutes of Technology.



Comparison between a state-of-the-art cosmological galaxy formation simulation (bottom) and a real face-on spiral galaxy (top). In both images gas is colored red and stars blue.

Appendix 3: List of acronyms

ALMA	Atacama Large Millimetre Array. A major collaboration between ESO, the US and Japan to construct and operate an array of 50 12-m millimetre-wave antenna, covering 200 km² of the Chajnantor plateau at 5000m altitude. The project has a total budget in excess of CHF 1 billion and is scheduled for completion in 2012.
BELA	BEpiColombo Laser Altimeter – a laser altimeter on board the ESA mission BepiColombo to study the planet Mercury.
CHEOPS	Characterising ExOplanet Satellite. – the first small mission in ESA's science programme dedicated to search for exoplanet transits using high-precision photometry. CHEOPS is jointly led by ESA and Switzerland.
CTA	Cherenkov Telescope Array – a ground-based instrument for the detection of high energy gamma-rays.
DES	Dark Energy Survey – a catalogue of the sky over 5000 degrees to probe the Universe.
DESI	Dark Energy Spectroscopic Instrument – to measure baryonic acoustic oscillations and redshift space distortions.
E-ELT	European Extremely Large Telescope. ESO's medium term priority after completion of ALMA is the construction of a 40-m class optical-infrared telescope.
ERC	European Research Council.
ERIS	An Enhanced Resolution Imager and Spectrograph for the VLT.
EPICS	Direct imaging of exoplanet instrument candidate for the E-ELT.
ESA	European Space Agency.
ESO	European Southern Observatory. A partnership of 12 nations, including Switzerland, that operates numerous state of the art telescopes in Chile, La Silla and Paranal observatories.
ESPRESSO	A super-stable Optical High Resolution Spectrograph for the combined coudé focus of the VLT.
Euclid	An ESA medium class astronomy and astrophysics space mission.
ExoMars	An exo-biology mission to Mars. Its aim is to further characterise the biological environment on Mars in preparation for robotic missions and then human exploration.
FHNW	University of Applied Sciences of the North-West of Switzerland (Fachhochschule Nordwestschweiz).
FINES	Fund for developing astronomical Instruments ESO.
FISH	ERC Project to study the explosion mechanism and nucleosynthesis in supernovae and Hypernovae explosions.
FLARE	SNSF funding programme for large international projects.
Gaia	An ESA mission to obtain extremely accurate positions and photometry of approximately 1 billion stars in the galaxy.
GNSS	Global Navigation Satellite Systems.
GTO	Guaranteed Time Observation. Awarded to instrument developers to enable them to carry out specific science investigations with their instrument.
HARPS	High Accuracy Radial velocity Planet Searcher – an ultra high precision spectrometer operating on the ESO 3.6m telescope.
HIPPARCOS	ESA scientific satellite, launched in 1989 and operated until 1993. It was the first space experiment devoted to precision astrometry measuring high-precision parallax for over 100,000 stars.
HiRes	High RESolution spectrograph instrument candidate for the E-ELT.
HST	Hubble Space Telescope, a NASA-ESA orbiting 2.5m telescope, in operation since 1990.
Integral	ESA's gamma-ray observatory.
JUICE	JUpiter ICy moons Explorer – an ESA space mission to explore Jupiter's icy moons. Launch foreseen for 2022.
JWST	James Webb Space Telescope. The 6.5m successor to the HST (and also the Spitzer Space Telescope) due to be launched in 2018. The JWST will operate primarily in the 1-28 μm waveband.
LSST	Large Synoptic Survey Telescope – large aperture, fast, wide field survey telescope to image faint objects across the entire sky.
Metis	A mid-infrared imager and spectrograph candidate instrument for the E-ELT.
MIRI	Mid-InfraRed Imager. This is an instrument being built for the JWST by a European-US consortium, operating in the 5-28 μm waveband and performing both imaging and spectroscopy.
MOONS	Multi-Object Optical and Near-infrared Spectrograph – an ESO instrument for the VLT.
MUSE	Multi-unit Spectroscopic Explorer, a second-generation instrument for the ESO VLT, consisting of a 90,000 channel integral field spectrograph.
NGTS	Next Generation Transit Survey. An array of small robotic telescopes installed at Paranal, Chile.
NOEMA	A millimetre telescope composed of twelve 15m antennae located at 2500m altitude in the French Alps.
NORSAT-1	Small Norwegian satellite to investigate solar radiation, space weather, and ship traffic. Launch foreseen in 2015.
LISA-Pathfinder	ESA technology demonstration mission in preparation of a gravity-wave measurement mission. Launch foreseen in 2015
Plato	PLAnetary Transits and Oscillations of stars – an ESA mission to measure planetary transits and stellar oscillations. Launch foreseen in 2024.
Proba-3	ESA mission to demonstrate formation flying in space. Two paired satellites will form a 150m long solar coronagraph. Launch foreseen in 2018.
PRODEX	PROgramme de Développement d'Expériences scientifiques.
Rosetta	ESA mission to rendez-vous with a comet and follow it to study its physical properties and evolution on its orbit.
SERI	State SEcretariat for Research and Innovation
SKA	Square Kilometre Array – an international project to build the largest radio telescope in the world with a square kilometre of collecting area.
SNSF	Swiss National Science Foundation.
Solar Orbiter	An ESA mission dedicated to solar and heliospheric physics. Launch foreseen in 2017.
SPICA	Space Infrared Telescope for Cosmology and Astrophysics. A Japanese satellite to be launched in 2022
Spitzer	A NASA infrared observatory.
SPHERE	A second-generation instrument for the ESO VLT, designed to detect large Jupiter-like planets around nearby stars.
VLT	Very Large Telescope: The four 8-m telescopes operated by ESO at Paranal Observatory.
VLTI	Very Large Telescope Interferometer: The four telescopes of the VLT when linked together interferometrically to give exceptional resolution on bright sources.
WIMP	Weakly Interacting Massive Particle.

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