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Future Ground-Based Solar System Research: a Prospective Workshop Summary

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Abstract The article tries to provide a perspective summary of the planetary science to be performed with future extremely large telescopes (ELTs) as an outcome of the workshop on 'Future Ground-based Solar System Research: Synergies between Space Probes and Space Telescopes' held on 8–12 September 2008 in Portoferraio on Isola d' Elba, Italy. It addresses science cases on solar system objects that might challenge the capabilities of ELTs and that provide a major step forward in the knowledge and understanding of planetary system objects per se and all populations. We also compile high-level requirements for such telescopes and their instrumentation that should enable successful ELT usage for research on objects in the Solar System, the 'disturbing foreground to real astronomy'.

Keywords Solar system science · Future ELTs

1 Research Goals of Planetary Science

The overall goals of research in planetary science are easy to define. They are:

(1) the description of our own planetary system, how it works, how it was formed and how it evolves
(2) the comparison with other planetary systems
(3) the search for life—at the end for intelligent life—in the universe

Goal (1) was, is and will be the area for many active research programs in planetary sciences in the past, nowadays and in the future. However, with the discovery of more than 200 exoplanet systems, the planetary system around the Sun has lost uniqueness and became one among many others. Thus, in the future, questions on the formation and

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evolution of planetary systems will become more important, and also in particular why and how our own one became as it is. The search for life forms is intimately related to planetary science, since the only life known so far is found on a planet (the planet Earth). And planetary bodies are expected to provide the venue for the appearance of life, certainly in our own solar system and possibly elsewhere. Searching for life and where and when it has formed is an implicit ingredient in planetary science though at present not considered a focal point of such research, but with great prospect to get there.

2 Planetary Spaceflight Missions

Since more than 40 years, planetary science is done to a large extend also via in situ explorations through spaceflight missions. All planets have been visited, comets and asteroids as well, and only a few object types have not yet had the pleasure to be investigated by a man-made spacecraft. Despite the more than 60 space mission to solar system bodies (excluding the Moon) and the success achieved through this kind of planetary system exploration, it should be noted that spaceflight exploration of the planetary system focuses on detailed studies of a few objects and from a close distance. In the near future (i.e. until the end of the second decade of this century), this kind of research will provide new scientific anchoring points for Mercury, Mars, Jupiter and/or Saturn, comets, asteroids and even Pluto, now considered a Kuiper Belt object.

The task of Earth or ground-based observations is to provide the context science for the planetary exploration. Earth-based telescopic observations are the only means to accomplish this goal. This important research has two facets, i.e. (1) to provide global-scale information, mostly on planets, which is difficult to achieve through in situ exploration and (2) to provide characterizing information on object types like comets, asteroids, Kuiper Belt objects and satellites, which is otherwise impossible to collect for cost reasons. It should be noted that the research listed under item (2) above deals with bodies that are usually considered to be 'closest' to the formation era of the planetary system.

Relevance and importance of telescopic observations from Earth for planetary science may be less obvious to colleagues who are a bit further away from this kind of research, though still close, i.e. the 'real astronomers' who may think that planetary science means 'have a look by a space probe' and the 'spaceflight people' who may think that getting telescope time is a 'piece of cake' compared to the cost of a space mission (the cost of ground-based telescope time invested in planetary science amounts certainly to several million EUR per year).

3 Prospects of Future Ground-Based Solar System Research

When describing prospects of future ground-based solar system research, one has to consider (a) that 'future' means by the time the next generation of telescopes will come on-line (b) what kind of extremely large telescopes and instrumentation will be available, and (c) what might have been achieved in planetary science in the meanwhile. To simplify these considerations, we follow the task of the workshop and focus on an extremely large telescope (ELT) of the type the European Southern Observatory ESO is currently studying. We furthermore assume that this ELT may come on-line towards the end of the next decade (i.e. shortly before 2020). Contributions from such a telescope for solar system research may come for the exploration of the existing inventory of the planetary system, from the description of physical parameters of the bodies, for the global physical processes therein, for the understanding of its formation and evolution as well as for life science aspects in the planetary system.

3.1 Inventory of the Planetary System

PanStarrs, Large Synoptic Survey Telescope LSST, Gaia and other survey projects will establish a very comprehensive inventory of objects in the planetary system. This will include objects and their orbits, magnitudes, colors, and they will certainly provide the global and detailed view on the existing populations and their orbit dynamics. An ELT may have little to add except that it may be very powerful in exploring object populations beyond the detection limit of these surveys, i.e. either because these objects are farther away or they are too small to be detected by the smaller telescopes. ELT occultation experiments (presentation by F. Roques) using fast photometry over a decent field of view (diameter at least 1 arcmin) can be the pathway to a step much beyond the limits of the above mentioned inventory surveys since it has the potential to discover very distant (beyond several 100 to 10,000 AU) and rather small planetesimal-like objects.

3.2 Physical Characterization of Planetary System Objects

Measuring fundamental parameters of solar system objects like size, albedo, shape, rotation, mass, density, thermal properties, represents the important first step for the physical characterization of in particular the smaller population of objects, i.e. asteroids, cometary nuclei, Kuiper Belt objects (KBOs) and satellites. Covering a significant part of the respective population by such data will allow to explore population properties and the context with other (for instance dynamical) parameters that potentially will illuminate the formation and evolution of the particular group of objects. One can expect that a huge database on size, shape, albedo, rotation will exists for asteroids by 2020. However, high-resolution near-IR ELT imaging (order of 0.01 arcsec resolution) of cometary nuclei (presentation by A. Fitzsimmons) and KBOs (presentation by W. Grundy) will provide sufficient spatial resolution to resolve the body shape of typical medium size representatives of the two populations. Even better and more important contributions will come from such ELT observations of binary systems (presentation by K. Walsh), since they will allow constraining the masses and—if size information is available—the bulk density of the bodies. This approach applies to binaries in all small body populations in the planetary system. Similarly, thermal properties can be explored by mid infrared high resolution imaging (presentation by T. Müller). Finding binaries/multiples through ELTs may be of interest for the close pairs and small size objects. At present, it is uncertain to which extend survey type work for binary searches using ELTs may be of particular interest, since binaries are nowadays frequently detected by other means (i.e. through lightcurve studies using smaller telescopes).

3.3 Composition of Small Bodies

The surface mineralogy of small bodies like asteroids and KBOs can be assessed by low-dispersion IR spectroscopy using existing large telescopes or the James Webb Space Telescope JWST in the future. ELTs with their high spatial resolution capabilities will open up the pathway for the exploration of body surfaces in two dimensions, even for small objects like asteroids, KBOs, and satellites (presentation by W. Grundy). Again, the most interesting wavelength range will be the IR domain, and both imaging and low dispersion instrumentation will be most adequate.

3.4 Physical and Chemical Processes

Space mission to comets and KBOs (Rosetta and New Horizons) will allow the exploration of physical and chemical processes involved in the evolution of these small icy bodies in the solar system. A more difficult task and usually out of range for spaceflight missions (since too close) is the exploration of planetary atmospheres on a global scale, the chemical cycling of the gases therein and the stability of these processes and of the atmosphere as a whole (presentation by T. Encrenaz). It is expected that the Herschel space telescope and the Atacama Large Milimeter Array ALMA will approach some of the related issues. However, ELTs utilizing high spatial resolution imaging and high dispersion IR spectroscopy will enable a quantum leap in the analysis and understanding of these important scientific questions. Clearly, the remote, but global viewing at high spatial resolution will provide the pathway for this progress.

3.5 Solar System Formation

Of immediate interest are the starting and the formation conditions for the solar nebula and the characterization of the protoplanetary disk as well as the so called ‘planetesimal era’. In particular the latter two can be considered important anchoring points for the understanding and modeling of the overall formation process of the solar system. Recently, mid-IR spectrocopy (and lab measurements of returned dust samples) has revealed the co-existence of amorphous and crystalline silicate grains in comets; the former grains are assumed to represent the radiation processed dust originating from the collapsing cold protostellar cloud, while the latter ones are meant to be formed in a very hot environment, possibly very close to the early Sun. The coexistence of both silicate forms in comets could imply that an efficient radial mixing process of dust must have been in place during some period in the existence of the protoplanetary disk before comets were formed, if the dust cannot be formed in situ (for instance by electrical discharging) at larger distances from the Sun. So far, the two forms of silicate dust have been measured in three brighter comets since reaching proper signal-to-noise ratios for detection is very difficult using existing observing equipment. The light collecting of an ELT equipped with a medium dispersion mid-IR spectrograph can change this situation drastically. It will be of interest to see to which extend the mentioned phenomenon is omni-present in comets or whether heterogeneity is detected. Both findings would be with outstanding impact for formation models of and for the unterstanding of the physical processes in the protoplanetary disk.

A real bonanza of new planetary science could be discovered by ELTs equipped with a high dispersion IR spectrograph in the 3–5 μm range (presentation by M. Mumma). In this wavelength region one can explore the composition of cometary ices through molecular coma gas spectroscopy. Being a by-product of these observations, nontheless equally important, it will be possible to assess and constrain physical conditions at the time of formation of comets in the outer solar system by measuring ortho-to-para ratios of certain molecules as a tracer of the spin temperature of the species, and thus possibly the temperature of the formation region of the body, and the isotopy of molecules as an indicator for the physical processing in the outer formation disk. All these measurements will not be done the first time with ELTs, since they are possible already with existing or future large telescopes (Keck Telescopes, Very Large Telescope VLT, Atacama Large Milimeter Array ALMA), but only for a very limited number of bright objects. Only the ELTs can explore a large enough sample to enable statistical and context studies such that one can hope to get a synoptic and global view of the gas chemistry and physical conditions in the outer planetary formation disk.

3.6 Water on Earth and Life in the Universe

The origin of water on Earth is a long lasting debate with still open conclusion (presentation by K. Meech). A likely scenario is the import of water to Earth by major impacts after the planet had cooled down and a crust had formed. Comets and asteroids are considered as the major cosmic contributors here. The role of comets for water on Earth can be assessed through D/H isotopy measurements of these abundant gas species in the cometary coma by using for instance high dispersion mid-IR spectroscopy (or alternatively radio wavelength and in situ measurements). This mid-IR technique is about to be established using existing large telescopes (in the future also the Alma submm facility). So, one can hope that significant progress is made by the time the ELTs will go ‘on sky’. However, if the question is not yet solved by then, since for instance the number of comets measured is still too small, the ELT will have the capability to reach a considerably larger number of objects such that by a systematic survey of medium bright objects (>10mag) the comet contribution to the water on Earth could be solved. Published results for about a handful of comets that were measured, indicate an at least twice as high D/H ratio compared to terrestrial ocean water, which argues for a scenario that comets—if at all—may not have been the only contributors to water on Earth.

Even more challenging is the question for the search of life or indicators of life in the universe. We are only at the beginning of this exploration when it comes to our own planetary system which—and there is no doubt—contains a planet that carries many life forms. Whether life on Earth was triggered (or even imported) through proper ingredients from space, should be addressed by future observations. Spaceflight experiments (Rosetta, ExoMars, sample return missions) will try to provide first answers for selected objects in the planetary system. It would be the task of telescopic observations and proper measurement techniques to provide alternative and sensitive—not yet existing—techniques for the detection of (pre)biotic material in space (beyond simple molecules like HCN). ELTs will be the future platforms for such searches, for sure not only in our own planetary system[1].

4 Requirements for Planetary Research with ELTs

It looks like that planetary research does not impose any specific and new technical requirement that would drive the design of an ELT. The prinicpal technology and equipment that is needed and the knowledge how to implement it for best usage is already available and is implemented at existing telescopes.

[1] The question of intelligent life in the universe may have an answer already that is given in a Calvin & Hobbs cartoon: Calvin to Hobbes while walking through a destructed forest: ‘I was reading about how countless species are being pushed toward extinction by man’s destruction of forests.’ and he continues: ‘Sometimes I think the surest sign that intelligent life exists elsewhere in the universe is that none of it has tried to contact us.’

What is needed for ELTs to support planetary science in the future? At the first place, it is the capabilty to track and autoguide on moving targets. For ELTs this includes parallel usage of adaptive optics locked on the moving target, since spatial resolution and signal-to-noise improvement will be key for successful planetary science at these telescopes.

The instrumentation needed for planetary science covers the (0.3)1–20 μm wavelength range and includes imaging and spectroscopy options. The instruments considered for the ESO ELT appear to be in general very adequate for competitive and challenging research of planetary system objects—maybe with the exception of the absence of a workhorse-like FORS-type instrument for the visible wavelength range and possibly a fast photon counting system. Since L, M and Q band applications are important for planetary research, the quality of the atmosphere above the ELT site may become an important parameter for successful measurements (or frustration of the scientists). For the high dispersion spectroscopy application in planetary science wide wavelength coverage is clearly preferable in order to allow parallel measurements of many species and thus the exclusion of time variability in the measured mixing ratios.

Last, but not least: Planetary science does not—yet—appear as a prominent science case for the (ESO) ELT and only in a single instrument it is included as an instrument science case. It is the task of the planetary science community to strengthen their own research case for the ELT in order to make sure that the capabilities of future ELTs will be available for research applications in the solar system.