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Observational Astronomy: Status 2020

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Abstract—Achievements, prospects, and problems of modern observational astronomy are briefly discussed.

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INTRODUCTION

Astronomy is an observational science [1]. Although direct investigations of objects in the Solar System by means of space planetary probes became possible in XX century, this occurs occasionally, is expensive, and therefore is not affordable for all countries [2]. On the other hand, state-of-the-art technologies opened access to optical telescopes not only for professional astronomers but also for amateurs, who make their own contribution to common effort aimed at studying the Universe [3]. Even in exploring the Solar System, a dominant flow of data comes from ground-based optical observations, and only in some individual directions do space probes supplement them with (invaluable!) data from direct measurements [4]. In all probability, investigations into the objects beyond the Solar System will have had for a long time to rely on methods of remote observations [5].

Astronomers aspirations to be able to monitor the whole sky in all ranges of the electromagnetic spectrum (and in other channels as well!) at the highest possible angular, time, and energy resolutions, reliably saving in archives arrays of data obtained in this way. We gradually approach an implementation of this hope, even though some unresolved problems have yet remained.

SUCCESSES OF OBSERVATIONAL ASTRONOMY

In a sense, the reach of telescopes, optical and radio ones, extends to the boundaries of the Metagalaxy, and we now have a fairly good idea of the "geography" of the Universe [6]. Observations in all ranges of the electromagnetic spectrum have presumably revealed all basic types of radiating cosmic bodies. Anyway, we were able to find all cosmic objects predicted theoretically, including neutron stars; black holes (radiation arises near them); giant gaseous molecular clouds; planets around other stars (exoplanets or, alternatively, extrasolar planets); and, finally, brown dwarfs, which are a link between planets and stars.

In addition to the electromagnetic channel of observations, reliable results have already come from other channels—the neutrino channel and gravitational-wave one [7]. The total flux of solar neutrinos was detected reliably, whereby the theory of the inner stellar structure was confirmed independently. Concurrently, this revealed the presence of neutrino oscillations, which proved that the neutrino, earlier an "impalpable" particle, has a nonzero rest mass. Gravitational waves were discovered by means of direct detection, and their sources in the form of the merger of massive relativistic objects were indicated with a high probability. In addition to these theoretically predicted phenomena, observations unearthed unexpected substances—dark matter and dark energy, whose analysis is still under way.

It can be stated that solving the problem of cosmography, which is a descriptive part of the science studying the Universe, had been nearly completed toward the end of XX century. No new types of cosmic objects have been found over the first two decades of the new century, even though new phenomena have of course been discovered. They include radio outbursts and gravitational-wave pulses. However, astrophysical theorists seek the explanation of these phenomena among the possible manifestations of already known objects, such as neutron stars and black holes.

It seems that the potential of observation goes ahead of the imagination of the theorists, since there is no request from them to perform searches for radically new radiating objects. Thus, the astronomers

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have at last grounds to believe that they perceive quite comprehensively the realms of their investigations, the spacetime scale of the Universe, and the whole variety of the objects that populate it. As for dark-matter carriers, the potential of observational astronomy for their searches is nearly exhausted, so that further advances are expected from methods of experimental physics.

UNSOLVED PROBLEMS OF OBSERVATIONAL ASTRONOMY

We now address the question of what hinders an implementation of astronomers' dream. We are still far from the ability to monitor the whole sky, since the area of the celestial sphere is 41 253 degrees squared, which is equal to 210 100 areas of the lunar or solar disks, whereas the area of the field of view of the majority of large telescopes is substantially smaller than the lunar-disk area. Of course, there are moderately small wide-angle object lenses (all-sky cameras), but their angular resolution and penetration power are insufficient for solving serious astronomy problems. In view of this, optical schemes of sophisticated mirror–lens telescopes of large diameter (in excess of 8 m) with a large field of view (about 10 degrees squared) have already been calculated, and such telescopes are being presently constructed. Instruments of this type will be able to fix the image of the whole sky within several clear nights, covering objects of apparent stellar magnitude up to 24 or 25.

In addition to scanning the sky, the astronomer should study in detail individual objects, in which case optical astronomy runs into a number of problems. Up to the middle of XIX century, the human eye had been the only light receiver; therefore, advances in astronomical observations were due to the improvement of the quality and size of the telescope's object lens. After the advent of the photoprocess and spectral analysis, advances in astronomy had come to hinge, up to the first decades of XX century, upon the quality of photoemulsions and the mechanical system of telescopes, which permits high-precision guiding in the course of long exposures. When limits were reached along these lines inclusive, the telescope diameters were magnified further to values of 2.5 m, 5 m, 6 m, etc. However, photographic plates gave way to semiconductor matrices, and the growth of their quantum efficiency permitted further advances without creating new telescopes. Upon the slowdown of the improvement of the photoreceiver efficiency, it became necessary to revive the creation of larger telescopes: 8 m, 10 m, 12 m . . . .

The quantum output of photographic matrices has already reached a nearly 100% level; therefore, further advancements require new telescopes 25 to 40 m in diameter—very expensive and highly technological ones. The construction of such telescopes is indeed under way now. The Extremely Large Telescope (ELT) located on top of Cerro Armazones in the Atacama Desert of northern Chile as part of European Southern Observatory (ESO) and designed to have an object-lens diameter of about 40 m and an effective area of about 1000 m^2 is the leading exponent among them. If successfully commissioned (in 2025, as is planned), it is expected to ensure a new breakthrough in astronomy at the end of the 2020s.

The Hubble Space Telescope has demonstrated a great improvement of the image sharpness in the absence of the distorting effect of the atmosphere. However, space telescopes are expensive, so that astronomers search for similar possibilities on the Earth. All best sites on the Earth for deploying telescopes have already been found and are being exploited. Therefore, technological solutions are required for further advances. The most promising among them is provided by adaptive optics. The correction of small seeing fields by means of controlled deformable mirrors and a laser guide star has already been mastered at the largest telescopes worldwide. Multilaser systems that would be able to correct large seeing fields are now in the wait list.

Although optical astronomy still holds the lead in collecting useful information, there are also achievements and problems in other ranges and observation channels. For example, the long-wavelength part of the radio range has so far remained unexplored, since waves of wavelength in excess of 15 or 20 m cannot penetrate through the ionosphere and reach the Earth's surface and since it is difficult to deploy long antennas in space (even though there were attempts to do this). There is a hope for creating long-wavelength telescopes on the far side of the Moon. The first experiment aimed at this purpose was performed in 2019 by means of the Chinese Chang'e-4 robotic spacecraft mission.

PROSPECTS OF OBSERVATIONAL ASTRONOMY

The basic lines of the development of observational astronomy nowadays and in the near future are the following:

(i) creation of systems of robotic telescopes for providing a fast response to short-term phenomena;

(ii) creation of large survey telescopes aimed at searches for small and far objects in the Solar System;

(iii) use of extra-atmospheric instruments for extending the range of the electromagnetic spectrum (in particular, to the region of long-wavelength radio waves);

(iv) multiobject spectroscopy for mapping the structure of the Universe;

(v) high-resolution spectroscopy for studies in the realms of astroseismology and searches for exoplanets;

(vi) creation of ground-based and space star coronagraphs for studying sky regions near bright stars (in particular, for studying exoplanet systems);

(vii) use of space platforms for high-precision astrometry and photometry;

(viii) refinement upon adaptive-optics systems;

(ix) refinement upon intercontinental very-long-baseline interferometers and creation of Earth—space interferometers in the millimeter and submillimeter ranges;

(x) improvement of the sensitivity of neutrino detectors via increasing their volume;

(xi) extension of the frequency range and improvement of the sensitivity of gravitational-wave detectors via creating cryogenic solid-state receivers (high frequencies) and large-scale systems in cosmic space (low frequencies).

CONCLUSIONS

The creation of robotic telescopes and large survey telescopes increases the flow of detected data by several orders of magnitude. The transmission and storage of these data within the Earth have not yet involved any problem, but the translation of data from space telescopes to the Earth already becomes a challenge. The processing of these data and the classification of these data is even a more severe problem.

For example, this is so in classifying variable stars and morphological types of galaxies [8, 9]. The number of professional astronomers in the world is not great—they are mostly members of the International Astronomical Union, which includes about 14 thousand astronomers. As long as there were thousands of new objects discovered annually, the astronomers were able to cope with the classification and preliminary investigation of these objects within the professional community. Since the beginning of XXI century, large photographic and photometric surveys have been presenting several hundred thousands of new objects, with the result that resort to the help of volunteers from amateur astronomers through the Internet becomes unavoidable. In the near future, however, there will appear hundreds of millions and even billions of new objects, and only self-learning artificial intelligence systems will be able to handle such data.

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