Astronomy

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Abstract

Full Text

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On the Application of Multistage Electron-Optical Light Amplifiers in Astrophysics

1. The solution of a number of problems in modern astrophysics requires a considerable increase in the sensitivity of the observational methods employed. Among such problems it is enough to mention spectral and photometric studies of flare stars, in whose atmospheres powerful nuclear processes sometimes unfold within a few minutes, as well as the spectroscopy of the faintest extragalactic nebulae and, in particular, the problem of refining the redshift, which should provide an answer concerning the metric of the universe.

Increasing the sensitivity of astrophysical apparatus can proceed in two directions. The first is an increase in the size of telescopes. As is known, the largest modern telescope is the five-meter reflector of the Mount Palomar Observatory, and it is difficult to think that in the coming years it will be possible to create telescopes with an aperture of another order of magnitude. It is therefore necessary to develop in every way the second direction—the development of recording methods in which the photon flux collected by the telescope is used with maximum efficiency.

One of such possibilities is the use of multistage electron-optical light amplifiers, described in work (1). These instruments possess a large amplification coefficient at a low level of their own noise and make it possible to record the effect of a single electron (2)*.

Let us consider some questions connected with the application of electron-optical light amplifiers in astrophysics. The resolving power of a multistage light amplifier is 10–20 lines/mm. This is approximately 5 times less than that of a photographic plate. In a number of cases, however, the latter circumstance is not so important as it may seem at first glance. To ensure equivalent resolution in the present case it is sufficient merely to increase the image scale by a factor of 5**.

Let us estimate the gain in the efficiency of use of the photon flux in comparison with the ordinary photographic method. We shall start from the condition of ensuring an accuracy of photometric processing of the material obtained of 10%, which approximately corresponds to the accuracy of ordinary photography under conditions of the maximum possible resolution. For this, in each element of the image with an area of 10^{-4} cm^2, determined by the resolving power of the electron-optical light amplifier, it is necessary to accumulate the effect from such a number of electrons as will ensure the necessary acc—ness of photometry determined by statistics. This corresponds to the effect of 100 electrons. For an antimony-cesium photocathode with a quantum yield of 0.1, this corresponds to 10^7 photons/cm^2.

A comparison with the ordinary photographic method should be made at the minimum blackening density of an ordinary photographic plate that ensures the specified accuracy of the measurements. However, for an approximate comparison it is sufficient to start from a blackening density equal to unity, which is obtained on modern high-sensitivity plates under the action of $4 \cdot 10^{10}$ photons/cm^2 (4).

Consequently, for the conditions considered, with identical image scales in both cases, the efficiency of the electron-optical method exceeds the efficiency of ordinary photography by approximately $4 \cdot 10^3$ times. Increasing the image scale on the photocathode of the light amplifier, which is necessary in order to equalize the effective resolving power of the two methods, will reduce the gain in sensitivity of the electron-optical method in comparison with an ordinary photographic plate to 160 times.

The comparative estimate of the sensitivity of the electron-optical method made in this case on the assumption that the resolvable square of the photographic plate is $4 \cdot 10^{-4}$ mm^2 is very stringent with respect to the light amplifier. In reality, when photometering photographs, the resolvable square cannot be less than 10^{-2} mm^2. Therefore the sensitivity of the light amplifier should be estimated as a quantity of the order of 1000.

The use of an electron-optical light amplifier in general cannot increase the penetrating power of a telescope, which is determined by the brightness of the night-sky glow.* It is obvious that, in order to make full use of the penetrating power, the effect of the light amplifier's own noise must be considerably less than

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* Another method that ensures the recording of individual photoelectrons is electron photography (3). This method possesses an exceptionally high resolving power and, with the low granularity of emulsions sensitive to electron impact, ensures the acquisition of very complete information about the object under study. However, the application of the method of electron photography is associated with considerable difficulties—the need to use a dismountable vacuum device and the consequent need to change photocathodes when recharging the device and to introduce the recording plate into the vacuum.

** It should be noted that, with an even greater increase in the image scale, it is practically possible here to achieve the same resolution as in the method of electron photography (3).

the sky background. It will be shown below that the light amplifiers employed satisfy this condition.

The high sensitivity of the light amplifier and the resulting reduction of exposure by hundreds of times (at equal effective resolving power) should substantially change the possibilities of astrophysical research. It opens the way to the study of rapidly varying processes in faint objects (flare, nonstationary, and variable stars) and makes it possible to raise substantially the utilization factor of astrophysical instruments. The latter is especially important for large, unique telescopes.

The reduction of exposure is of still greater importance for astrospectroscopy. Because of the unrealistically long exposures required when using the ordinary photographic method, the limit set by the glow of the night sky is practically not reached here. It may therefore be said that the use of light amplifiers in the field under consideration will in fact make it possible to increase substantially the real penetrating power of spectral apparatus.

2. The considerations presented above are confirmed by the results of the first experiments carried out by us at the Crimean Astrophysical Observatory of the Academy of Sciences of the USSR. Observations were made with a 500-mm meniscus telescope of the Maksutov system (MTM-500) with a relative aperture of 1/13 (^{5}). An electron-optical light amplifier was used which differed from that described in article (^{1}) only in that its input stage had magnetic focusing of the electrons. The light amplifier was powered from a stabilized high-voltage source. Its resolving power was 15 lines/mm. The antimony-cesium photocathode of the instrument had a sensitivity of 90 μa/lm and, during the experiment, was at room temperature. The image from the screen of the light amplifier was photographed with the aid of a lens of relative aperture 1/1.5.

* The maximum penetrating power for stars is practically achieved when the image scale of the turbulent disk of the star is equal to the resolving element in the apparatus used.

[Figure 1]

a *b*

Fig. 1. Photograph of the screen of the light amplifier with the photocathode darkened (*a*) and with the photocathode illuminated by the night-sky background (*b*). Both photographs were obtained with an exposure of 1 min. under otherwise identical conditions.

[Figure 2]

Fig. 2. Image of a stellar field in the Pleiades, obtained with the aid of a light amplifier. The serial numbers of the stars correspond to Table 1. Exposure 1 min.

[Figure 3]

a *b*

Fig. 3. Photographs of two extragalactic spiral nebulae, obtained with the aid of a light amplifier. *a*–NGC 278 (Sc; 1,2 × 1,2; $11^{\mathrm{m}}6$) and *b*–NGC 7332 (S; 2,0 and 0,3; $12^{\mathrm{m}}6$ pg). Exposure 1 min. The original negatives have been reproduced with an enlargement of 4.5 times.

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The nature and level of the intrinsic noise of the light amplifier were investigated in (^{2}). It is shown there that the dark current of the device consists of two components: a single-electron component and a multielectron component. The first component, due to thermionic emission from the photocathode, is negligibly small. Even at room temperature it is about $3 \cdot 10^{-18}$ A/cm^2 and cannot constitute a serious interference for observations. The level of the multielectron component of the dark current is much higher. However, owing to its strong dependence on the potential difference ΔV in a cascade (^{2}), it is possible to select such an operating regime for the light amplifier ($\Delta V = 6$ kV) that the number of multielectron groups coming from 1 cm^2 of photocathode is reduced to a few per second. At the same time the amplification factor of the device remains sufficiently large that the minimal signal—the effect of a single photoelectron from the first photocathode—can be photographed. Under these conditions the background on the negative, due to the intrinsic noise of the light amplifier, proved to be at least two orders of magnitude smaller than the background from the glow of the night sky. This may be judged from Fig. 1. Let us note that, as was to be expected, the background of the negative has a discrete character, caused by the quantum properties of the photoelectric effect and by the high amplification factor of the device which occurred in the present case*. Thus we see that the intrinsic noise of the light amplifier can indeed be neglected in comparison with the sky background. For an experimental determination of the gain in exposure time, photographs of the stellar field in the Pleiades were made both directly and with the aid of the light amplifier. The operating regime of the light amplifier was chosen to be somewhat more sensitive than is required for ensuring 10% photometric accuracy (see above). The resolving power in direct photography on a photographic plate (without the light amplifier) proved to be about 20 lines/mm. The scale in transferring the image to the photocathode of the light amplifier was 1 : 1. Under these conditions, in both cases the same photographic effect was obtained for stars of the 10th and 16th magnitudes, respectively. In the first case the exposure was 4 min, and in the second—1 min. Consequently, the gain in time when photographing one and the same star is about 1000-fold, which is in satisfactory agreement with the estimate given earlier.

Table 1

No.	Hertz. No.	m_{pg}
1	1070	$11{,}6^{m}$

Figure 4

Figure 1: Figure 4

No.	Hertz. No.	m_{pg}
2	1077	$13{,}5^m$
3	1113	$15{,}0^m$
4	1126	$16{,}2^m$
5	1134	$15{,}5^m$

Fig. 4. *a*—results of microphotometric processing of the negative of the nebula NGC 278 along the direction *cd*, indicated in Fig. 3a (microphotometer slit dimensions 0.15 × 0.17 mm); *b*—results of microphotometry of the background under the same conditions and in the same direction.

* The nonuniformity of the background, which is visible in Fig. 1b, is caused by the vignetting effect (at the edge of the field of view) and by the nonuniform sensitivity of the light amplifier over the field (in the center of the field of view). The latter, apparently, can be reduced to a few percent.

A photograph of a star field in the Pleiades, obtained with the light amplifier, is shown in Fig. 2. Table 1 gives the numbers of the stars according to the Hertzsprung catalogue (6) and their photographic magnitudes according to the same catalogue.

Figure 3 shows photographs, obtained by us with the aid of the light amplifier, of two extragalactic spiral nebulae. The structure of the nebulae is fairly clearly visible in the photographs. The results of a trial photometric reduction, without allowing for the sky background or for nonuniformities in the sensitivity of the light amplifier over the field, are presented in Fig. 4a, and the results of microphotometry of the background under the same conditions and in the same direction—in Fig. 4b. The root-mean-square fluctuation of the background (in intensities) is about 5%.

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