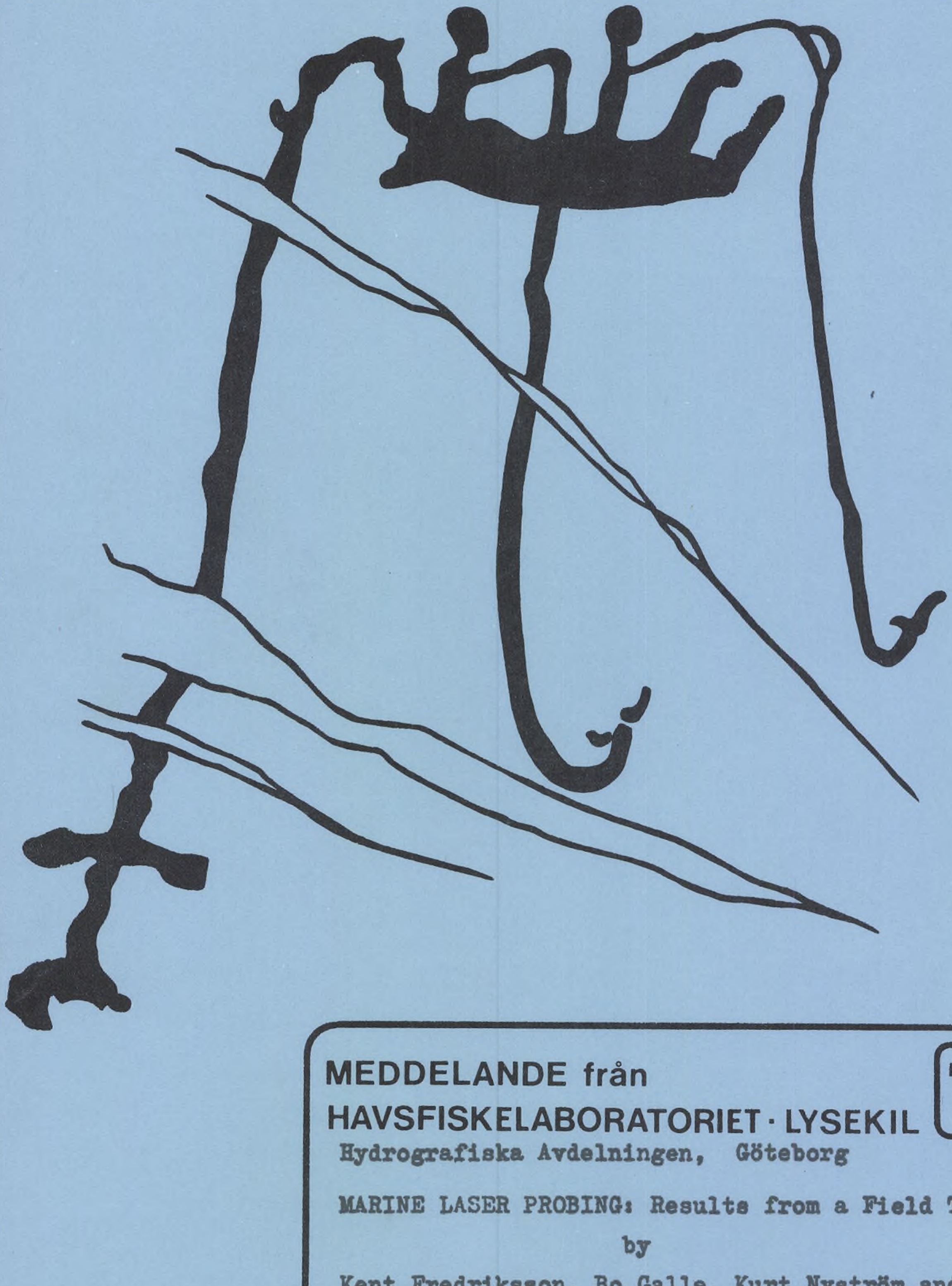
Ödsmål, Kville sn, Bohuslän

Hällristning Fiskare från bronsaldern	Rock carving Bronze age fishermen



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MARINE LASER PROBING: Results from a Field Test

by

Kent Fredriksson, Bo Galle, Kurt Nyström and Sune Svanberg
CHALMERS Department of Physics

and

Bertil Öström
NATIONAL BOARD OF FISHERIES
Hydrographic Department

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K. Fredriksson, B. Galle, K. Nyström, S. Svanberg
Department of Physics, Chalmers University of Technology
S-402 20 Göteborg, Sweden

and

B. Öström
National Board of Fisheries, Hydrographic Department
S-403 10 Göteborg, Sweden

Abstract:

A pulsed laser system was used together with an optical receiver in marine laser probing experiments during a field test onboard the research vessel "Argos" on the Swedish west coast. Using laser pulses in the green wavelength region, bathymetric measurements against a white screen and against live fish in cages were made using laser techniques. An algal bloom during the experiments generally excluded the observation of an echo from the screen at depths larger than 5 m. Signals from fish were observed only for the first two meters. Using ultra-violet laser pulses, experiments with laser-induced fluorescence were performed. Natural water as well as artificial oil-spills and tracer dye spills were investigated. Measurements of water fluorescence were made both when the ship was moored and when it was moving in open sea. Conclusions from the field test are presented.

1. Introduction

Presently the potential of lasers for different kinds of marine probing is being investigated at several laboratories. We have recently performed laboratory studies of both laser-induced fluorescence in materials of interest for the marine environment (1) and of under-water laser ranging (2). In this paper we report the results from a field test onboard a research vessel, where the techniques used in the laboratory were put to work under realistic conditions.

The main interest for laser probing of the marine environment stems from the challenging possibility of applying the technique from an aircraft to provide a convenient coverage of large sea areas. Short laser pulses are then transmitted downward towards the water and backscattered light is collected by an optical telescope close to the laser. If laser light in the blue-green spectral region is used, the pulses can penetrate through the water and a bottom echo might be observed besides the surface echo. This is the principle for laser bathymetry. UV laser light can, while not penetrating the water, induce fluorescence at larger wavelengths from the water region close to the surface. Certain kinds of substances have a characteristic fluorescense-wavelength distribution, that can be used for identifying the substance. Mineral oils, detergents, pulp-mill waste products and algae are examples of materials that yield useful signals. The principles of laser bathymetry are discussed in detail in Ref. (1). Similarly, different aspects of laser-induced fluorescence experiments are illuminated in Ref. (2). These two papers also contain proper references to work performed at other laboratories.

The Swedish National Board of Fisheries has an interest to investigate the possibilities of locating shools of fish using laser techniques. If successful, such a technique would be very valuable for airborne large-area surveys of the fish stocks in the upper water layers. The technique would supplement echo soundings performed by Swedish research vessels in the mapping of the fishery situation in progress. Following encouraging tank experiments, where echoes from fish were recorded for depths of 10 - 15 m, it was decided to perform a field test on the Swedish west coast. The experiments were performed from the research vessel "Argos", operated by the National Board of Fisheries.

2. Field Test Planning

The present field test, performed during the time May 8-12 1978, was part of a study of potential applications of different remote-sensing techniques to Swedish fisheries. The study was organized by the Swedish Space Corporation under sponsorship of the Swedish Board for Space Activities.

After slight modifications of the laser probing system used in the previous tank experiments, the system was mounted on board the research vessel "Argos". A location at the Gullmar Fjord was selected for the experiment, providing a possibility for the vessel to moor over deep water. In Fig. 1 the ship is shown. Net cages were prepared to keep fish schools in position for the experiments and fish was brought in just prior to the test to remain alive and in good condition. The cages containing the fish schools were alternatingly used for the calibration of the echo sounding integrator of the ship and the two experiments were run in parallel during the test.

The oceanographical conditions during the test were unfortunately not very favourable. During most of the test period the Gullmar Fjord had a 1-2 meter deep brackish surface layer of high turbidity. At the same time there was an unusually heavy bloom of phytoplankton, further reducing the light penetration. These conditions heavily restrained the bathymetric measurements, while fluorescence studies could be performed without difficulty.

3. Laser Probing System

The laser probing system used in the present experiments is schematically shown in Fig. 2. It is similar to the one described in Ref. (2), and here only a brief descripton will be given. As a transmitter a pulsed nitrogen laser was used, either directly or after wavelength conversion in a dye laser. The nitrogen laser had a peak power of 400 kW in 10ns pulses at 337 nm. The dye laser, employing the dye 7D4TMC, was operated at 532 nm, where pulses of 40 kW peak power and 5 ns duration were obtained. The receiving telescope was of the Newtonian type with a 25 cm diameter primary mirror. The light, focused by the mirror could be divided in two channels and was detected by identical photomultiplier tubes after wavelength selection by means of interference filters. The ratio between the fluorescence light levels at the two selected wavelengths could be measured by a boxcar averager, which is a gated integrator, adjusted to the proper time delay, corresponding to the distance from the studied object. Alternatively, the full, time-resolved laser-radar signal could be recorded using a fast transient digitizer, sampling the signal from a single photomultiplier tube every 10 ns. Using a microcomputer system, several transients could be averaged to improve the signal quality. Recorded data could be read out on a strip-chart recorder.

The probing system was mounted in the main laboratory of the ship and operated through an open window. A 40 x 60 cm mirror mounted outside the ship body was used to fold the optical path of the system by 90° so that the sea right below the mirror could be probed by the system. The beam diameter at the surface was about 5 cm. Fig. 3 gives a view of the set-up in the laboratory, and in Fig. 4 a photograph of the ship side with the mirror arrangement is shown. The total path from the telescope to the water surface was 10 m, whereas the distance from the mirror to the surface was 5 m.

4. Bathymetric Tests

4.1. Measurements against a white screen

Before attempting any measurements on fish targets, the set-up was used in measurements against a white screen. The screen consisted of a 1 m x 1 m piece of white sailcloth, stretched over a metal tube frame. The screen, fastened by strings in its four corners, could be lowered to a suitable depth. It immediately became obvious that the visibility through the water was disturbingly low due to the algal bloom previously mentioned. Thus the echo of the screen tended to vanish before it got separated from the stronger surface echo. Clearly, this problem would have been considerably reduced if a system with a better range resolution had been used. However, this would clearly not have increased the attainable measuring depth, but would have made the observation of objects close to the surface easier. A partial remedy of the problem was to use the technique with crossed polarizers in the transmitted and detected light beams (2).

In Fig. 5 two curves illustrating single-pulse measurements against the white screen are shown. On this occasion the Secchi-disc visibility was about 4 m. Echoes at depths of 5 and 7 meters are seen. Each curve also contains a surface echo and a promt signal indicating the time of the laser shot. During most of the time the visibility was considerably worse and echoes from the white screen could not be observed below 3-4 meters.

4.2. Measurements on fish targets

On the occasions when the fish targets were available the visibility in the water was very poor. Thus the signal due to reflexes from the fish bodies were sufficiently strong to be detected only when the fish were kept in the surface layer. With the depth resolution available with our system the echo due to the fish then coalesced with the surface echo. The presence of the fish could still be detected as a change in the echo amplitude. In Fig. 6 single-shot traces for water only and for water with herrings swimming in the surface layer (0.5 m) are shown. In the figure a histogram of the echo strengths for 15 random shots on water only and 15 random shots on water with herrings is also shown. The influence of the fish reflexes is clearly to be seen.

In Fig. 7 a measurement on cod is illustrated. In this case the cod were swimming close to the bottom of the cage at about 2.5 m depth. A curve formed by averaging 9 individual traces is shown together with three correspondingly averaged traces for water only. A broadening of the surface echo due to the presence of the fish can be seen.

5. Fluorescence Measurements

Whereas the bathymetric measurements largely suffered from the poor visibility of the water, experiments on laser-induced fluorescence were not affected. In the fluorescence measurements, the intensity of the laser echo from the surface layer (~ 1 m) was measured in a suitably located wavelength band. The ratio of the intensities in two different bands could also be measured, as mentioned above. As a first example we show in Fig. 8 (two upper curves) the intensity of the fluorescence light intensity in a 10 nm wide band around 465 mm. During the registration, 10 liters of detergent solution (20 grams/liter) was discharged close to the probed water region. The optical whiteners added to normal detergents exhibit a strong fluorescence, peaked at 440 nm and rapidly falling off through the blue-green region (1). Also natural sea water has a fluorescence in the blue-green region with a peak at about 425 nm. This fluorescence gives a background level in the curves of Fig. 8. However, a strong increase in the fluorescence is noted when the water containing the detergent reaches the probed volume. As the concentration of the detergent gradually decreases due to action of waves and currents, the background level is again reached. The bottom curve in Fig. 8 shows a ratio registration. The signal level is proportional to the ratio between the fluorescence light levels in 10 nm wide bands around 465 and 565 nm. As the fluorescence-yield curves for detergents fall off much faster for increasing wavelengths than is the case for normal water, the presence of a detergent is detected by an increased signal level. This is a measurement of the slope of the fluorescence-yield curve, useful for identification purposes.If quantitative measurements are attempted the fluorescence intensity should also be monitored. For the particular case illustrated in Fig. 8. the direct monitoring at 465nm yields a better contrast than the ratio measurement.

Mineral oils also exhibit characteristic fluorescence. Oils are attractive for monitoring because they form surface films. Crude oils exhibit a rather flat fluorescence light distribution in the region 450 - 530 nm (2). The 337 nm exciting light from a nitrogen laser is totally absorbed by a film about 10 µm tick. Thus the maximum attainable light level is reached for a film of such a thickness. During this field-test we performed measurements of the fluorescence contrast ratio between a thick film of the crude oil Abu Dhabi and the integrated fluorescence from the sea-water column through which the laser light was quickly attenuated. At 465 nm the contrast ratio was found to be about 3.2.

Because of the flat fluorescence maximum for the crude oils ratio measurements for 465 and 565 nm, as discussed above, clearly discriminates between oil and water. In contrast to the detergents, the crude oils are thus characterized by a slow intensity fall-off for increasing wavelengths and ratio curves corresponding to the bottom curve in Fig. 8 would exhibit a decrease of signal when oil is present. We chose to measure the inverse ration instead, leading to a signal increase when an oilspill is detected. In Fig. 9 two curves are shown, illustrating the detection of oil-slicks, caused by discharging 1 cm^3 of Abu-Dhabi crude oil. The quickly spreading film was not thick enough to absorb the laser light, which penetrates into the water also yielding water fluorescence For an optically thick film a contrast ratio oil/water of about 3.5 would be expected, according to laboratory measurements.

All the measurements discussed so far were performed when the ship was moored. A rather weak wind was blowing causing only small to moderate waves. It is of considerable interest to investigate the influence of a rough sea state. We therefore performed measurements of the normal sea-water fluorescence at 465 nm when the ship was moving at a speed of about 13 knots.

In Fig. 10 two registration intervals are shown. The recordings were taken with an electronic time constant of 2 sec. In the left part of the figure a registration during cruise in comparatively calm waters is given. The curve contains zero-point check readings. It was noted that the additional sharp decreases in signal occured when the ship was rolling. On such occasions the streak of white foam from the ship bows, normally situated well outside the point where the laser beam hit the surface, came right up to the ship body and thus covered the measuring position. The decrease in fluorescence is clearly understandable as the multiple reflections in the foam bubbles (causing the foam to look white) prevent the light from reaching the bulk water. The fluorescence from the thin bubble walls is clearly negligible compared to the bulk water fluorescence. The influence of the foam is more clearly to be seen in the registration in the right part of the figure. This curve was taken in quite rough sea and the dips due to foam are much more frequent.

As foam bubbles on the surface obviously has a very strong influence on the recorded fluorescence-light intensity, curves like the ones shown in Fig. 10 are not reliable for drawing any conclusions on the water properties. However, by recording the ratio of the fluorescence light intensities at two different wavelengths the problem with the foam can be eliminated as both intensities are influenced by the foam in the same way. Influences of laser intensity drifts are also eliminated. The curve in Fig. 11 is proportional to the ratio of the fluorescence light intensities at 650-750 nm and 465 nm. The data was taken during a distance of 25 km as the ship approached its home port in Göteborg. The curve does not show strong variations. It should be noted that an increase in phyto-plankton contents would increase the signal level due to the 685 nm chlorophyll-a fluorescence peak (2). However, oil spills would be observed in the same way due to the flat fluorescence curve of oils compared to water. To distinguish between phyto-plankton contents and oil spills, one should study also a wavelength band around 610 nm.

6. Conclusions

The field test performed on board the "Argos" was a useful step in assessing the possibilities for practical marine laser probing. The importance of a reasonable visibility depth for sea water in order to be able to do useful bathymetric measurements was very evident during the test. However, our previous tank experiment, performed in water having twice the Secchi-disc visibility, have shown that reasonable measurements can be performed even with a laser of such a low energy as the one used. For a practical application, a frequency-doubled Nd : YAG-laser with a much higher pulse energy is the natural choice.

The fluorescence measurements were encouraging. Artificial spills could be detected with a good signal-to-noise ratio. The measurement of fluorescence light intensity ratios for two wavelengths was found to be very useful. Influences due to sea foam and laser intensity drifts could be eliminated. An optical multi-channel analyzer, simultanously measuring in a few wavelength bands, would be even more useful for fluorescence monitoring.

Acknowledgements

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2. K. Fredriksson, B. Galle, K. Nyström, S. Svanberg and B. Öström, Underwater Laser-Radar Experiments for Bathymetry and Fish-School Detection, Göteborg Institute of Physics Report GIPR-162, 1978.

Legends to figures

Fig. 1	The research vessel "Argos".
Fig. 2	Experimental set-up used in the bathymetry and fluorescence tests.
Fig. 3	Detection telescope and electronics in the laboratory onboard the research vessel.
Fig. 4	Mirror arrangement used to fold the optical path.
Fig. 5	Range resolved echoes from a white screen at different depths. The first peak is a prompt echo indicating the time of the laser shot. The second peak is the water surface echo, and the last one is the screen echo. The screen echo is enhanced in relation to the surface echo by letting the laser beam and the telescope axis form an angle with ray interception at the screen.
Fig. 6	Single-shot signals for water only and for water with herrings swimming in the surface layer. In the lower part of the figure a histogram of echo heights for 15 random shots for both situations is shown.
Fig. 7	Two curves, formed by averaging single traces from water only and from water with cod at about 2.5 m depth, respectively. The shadowed part of the figure is interpreted as the influence of the cod.
Fig. 8	Fluorescence signal from a detergent discharged into the sea as it spreads. The two upper curves are measured at 465 nm, whereas the bottom curve is a ratio between the signal at 465 nm and 565 nm, respectively.

Fig. 9 Fluorescence signal from slicks of crude oil as they spread.

Fig. 10 Fluorescence signal at 465 nm on two occasions as the vessel was on its way back to Göteborg The measurement to the left in the figure was performed in calm water, whereas the other measurement was carried out when the sea-state was comparatively rough.

Fig. 11 Measurement of the ratio between fluorescence signals in the blue and red wavelength region respectively, as the vessel approached Göteborg.

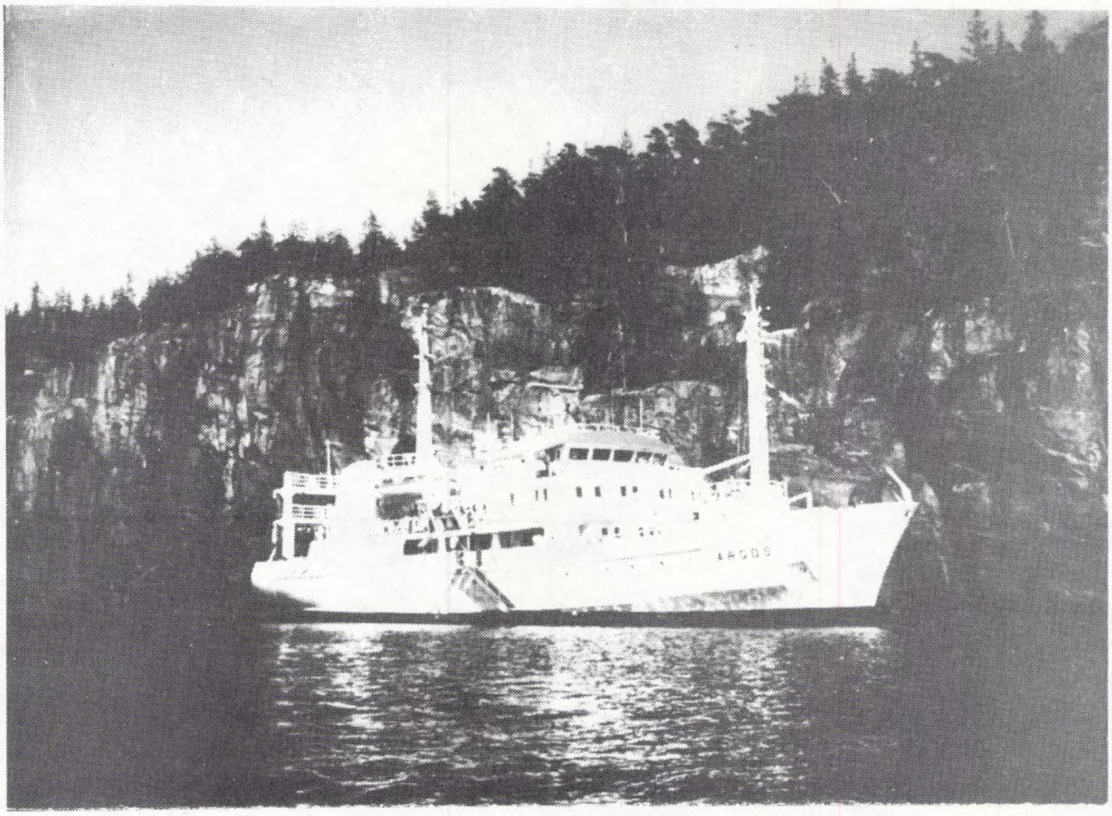
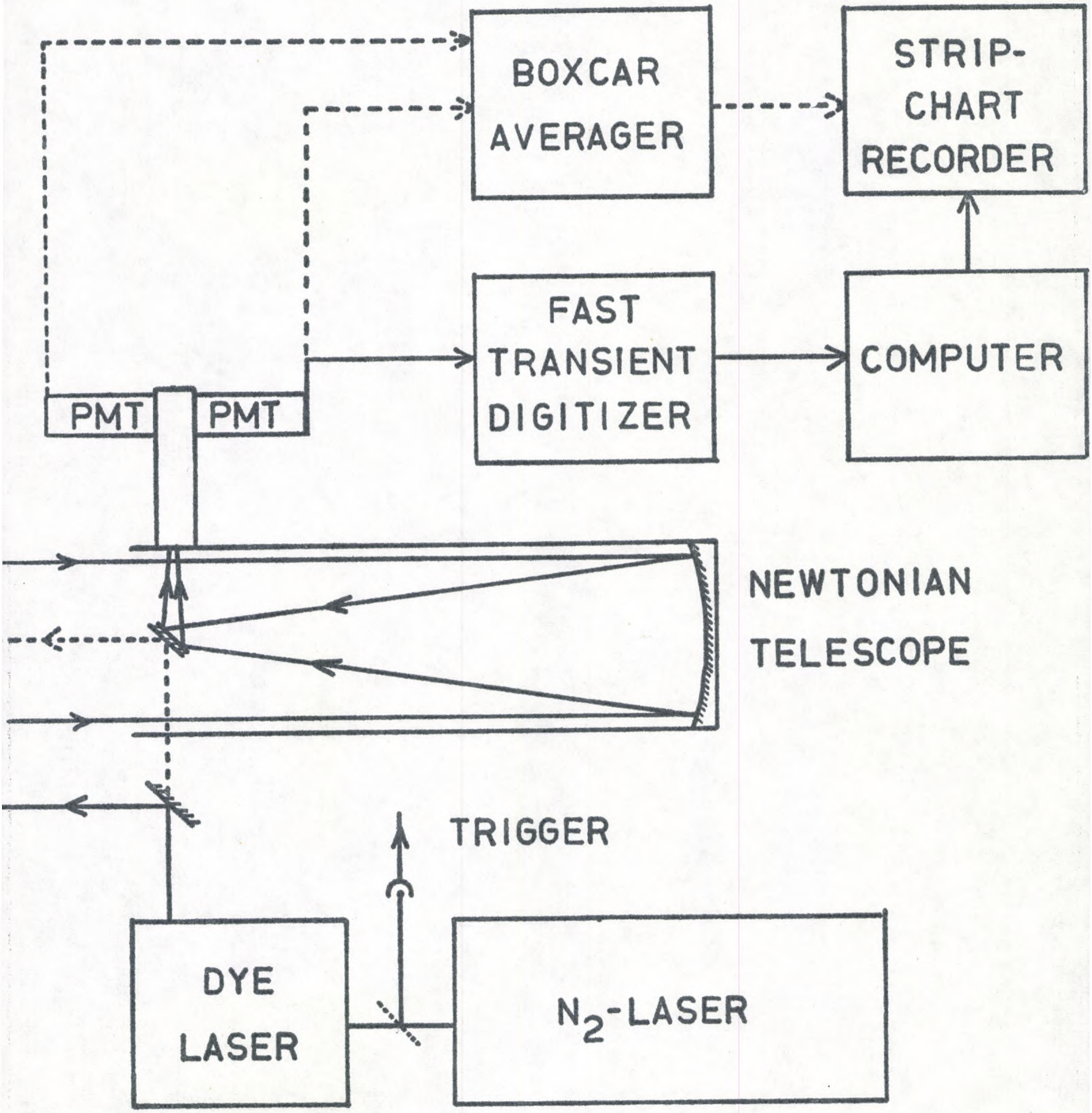


FIG. 1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TRIGGER
DYE
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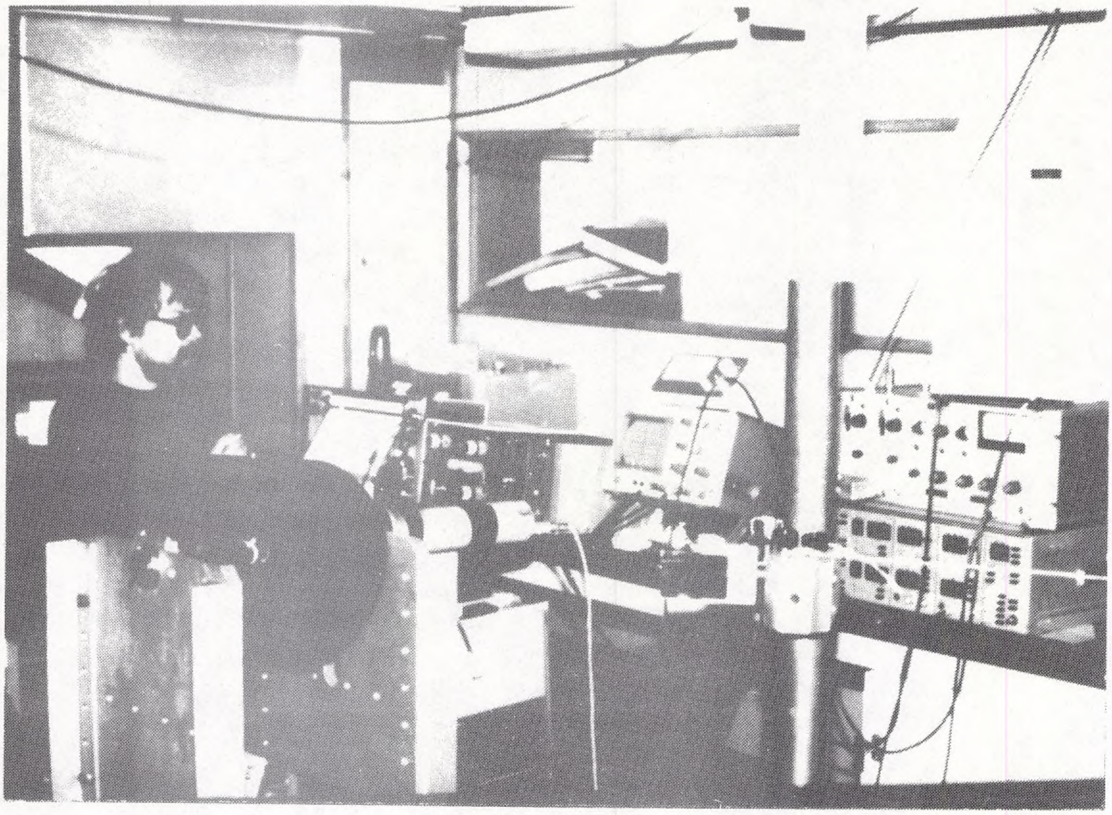
N$_2$-LASER

FIG. 2



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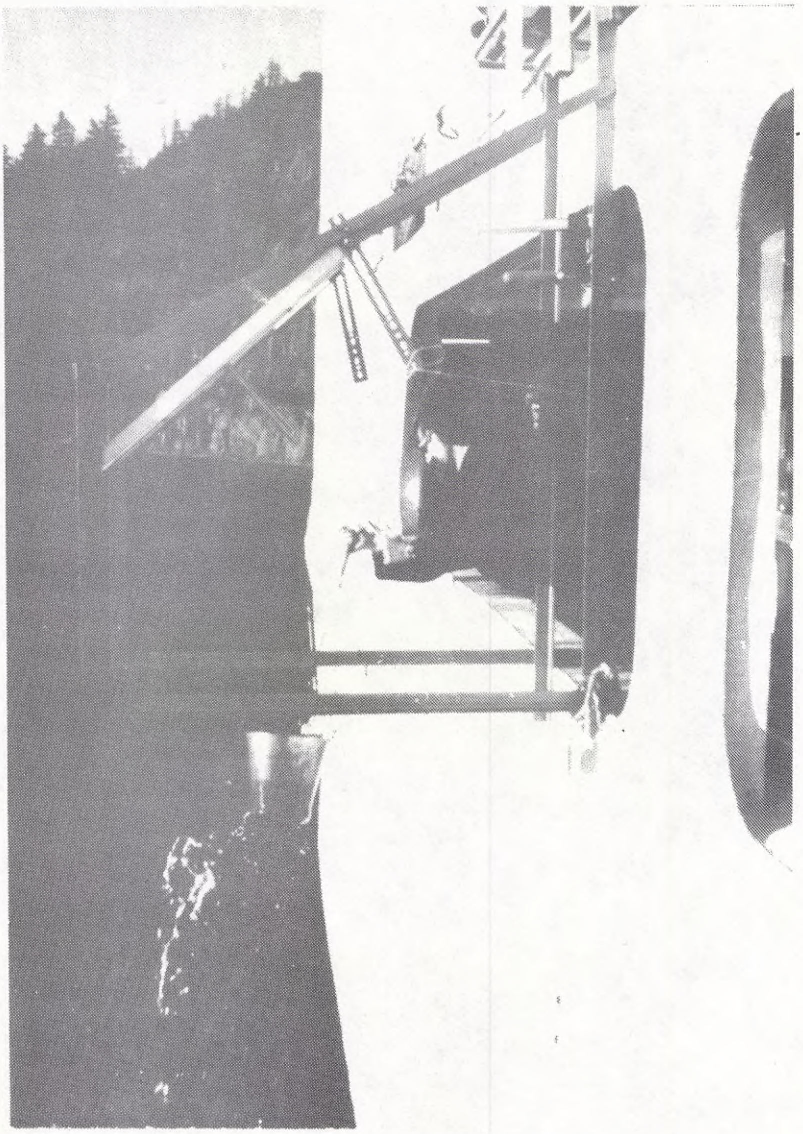

FIG. 4

FIG. 5

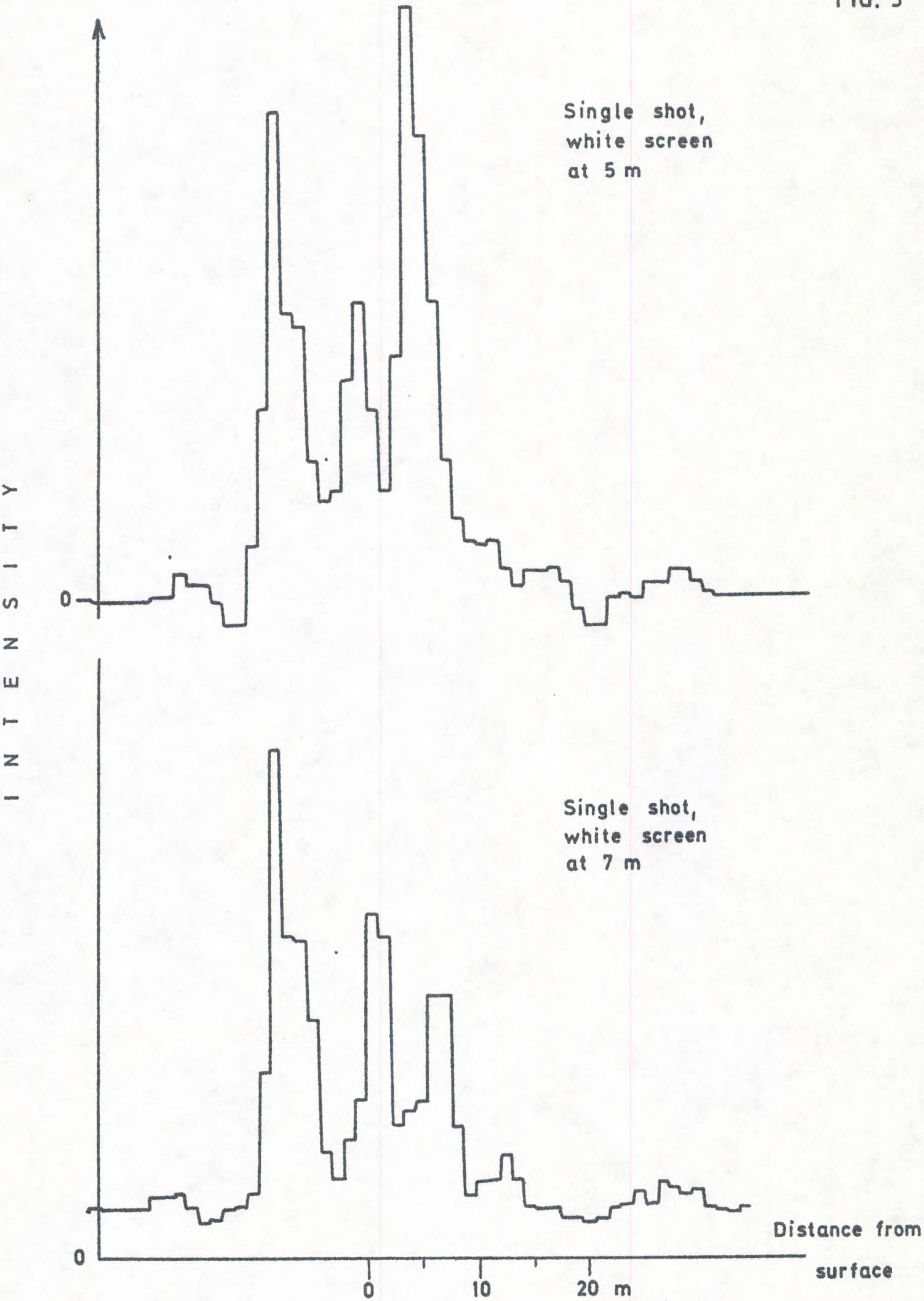

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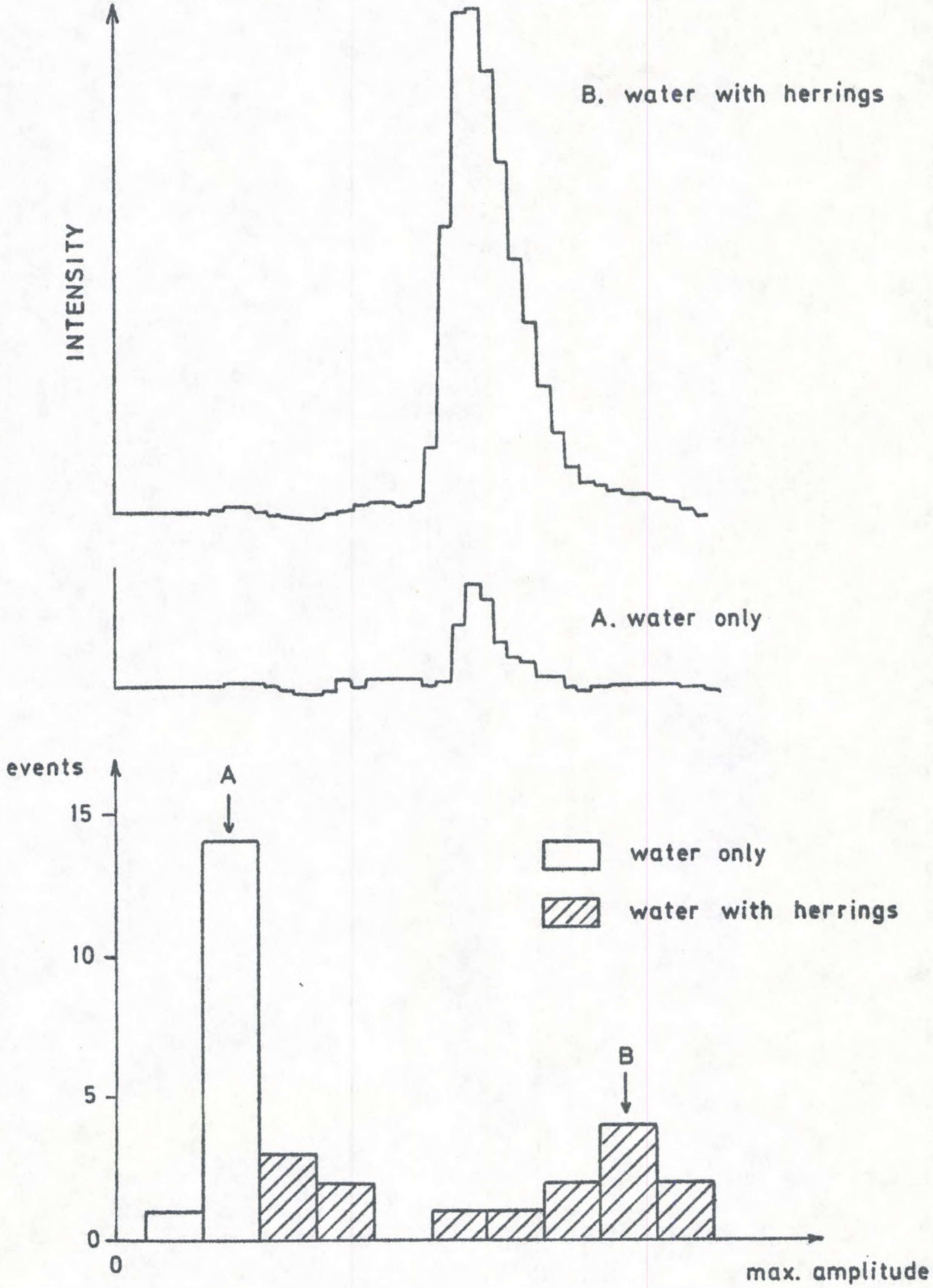
FIG. 6


INTENSITY
B. water with herrings
A. water only
events
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10
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▭ water only
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HyA /78 /

FIG. 7

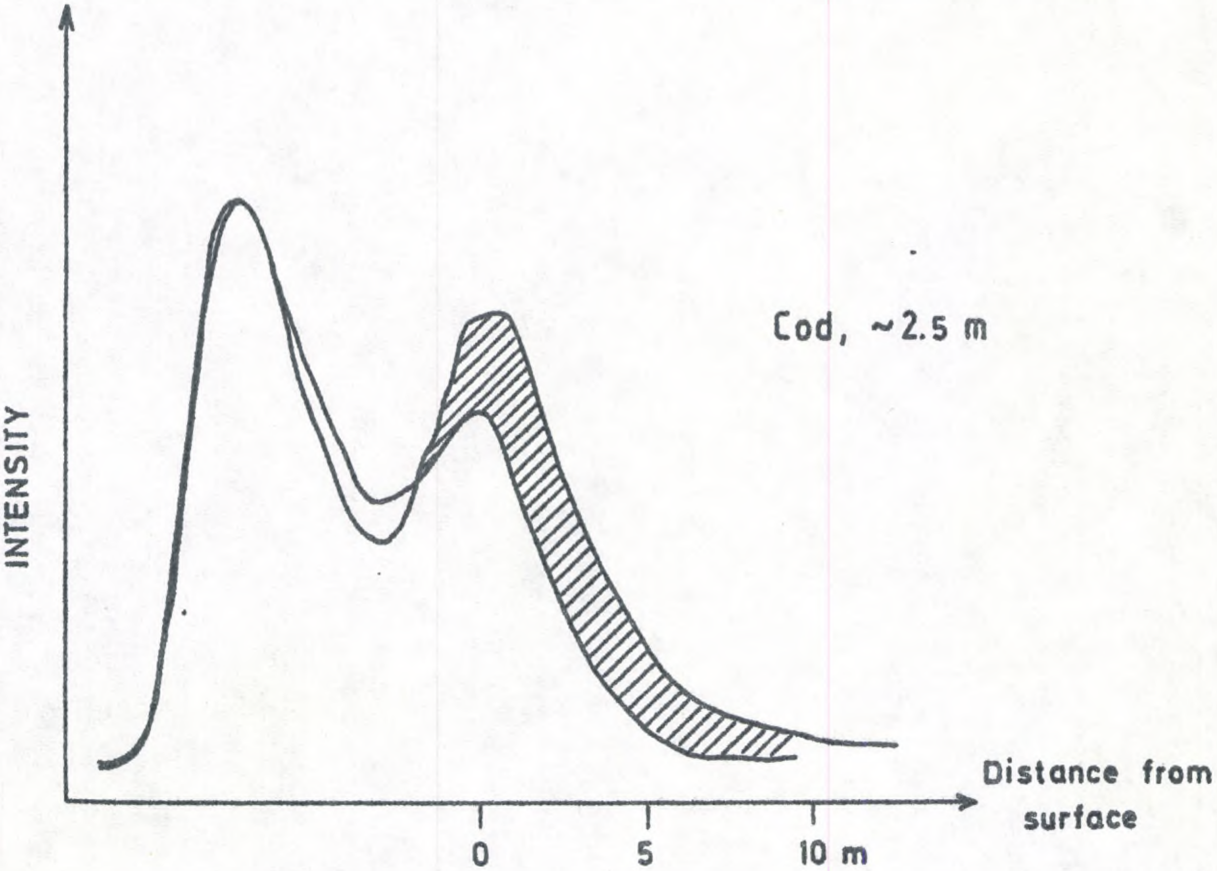

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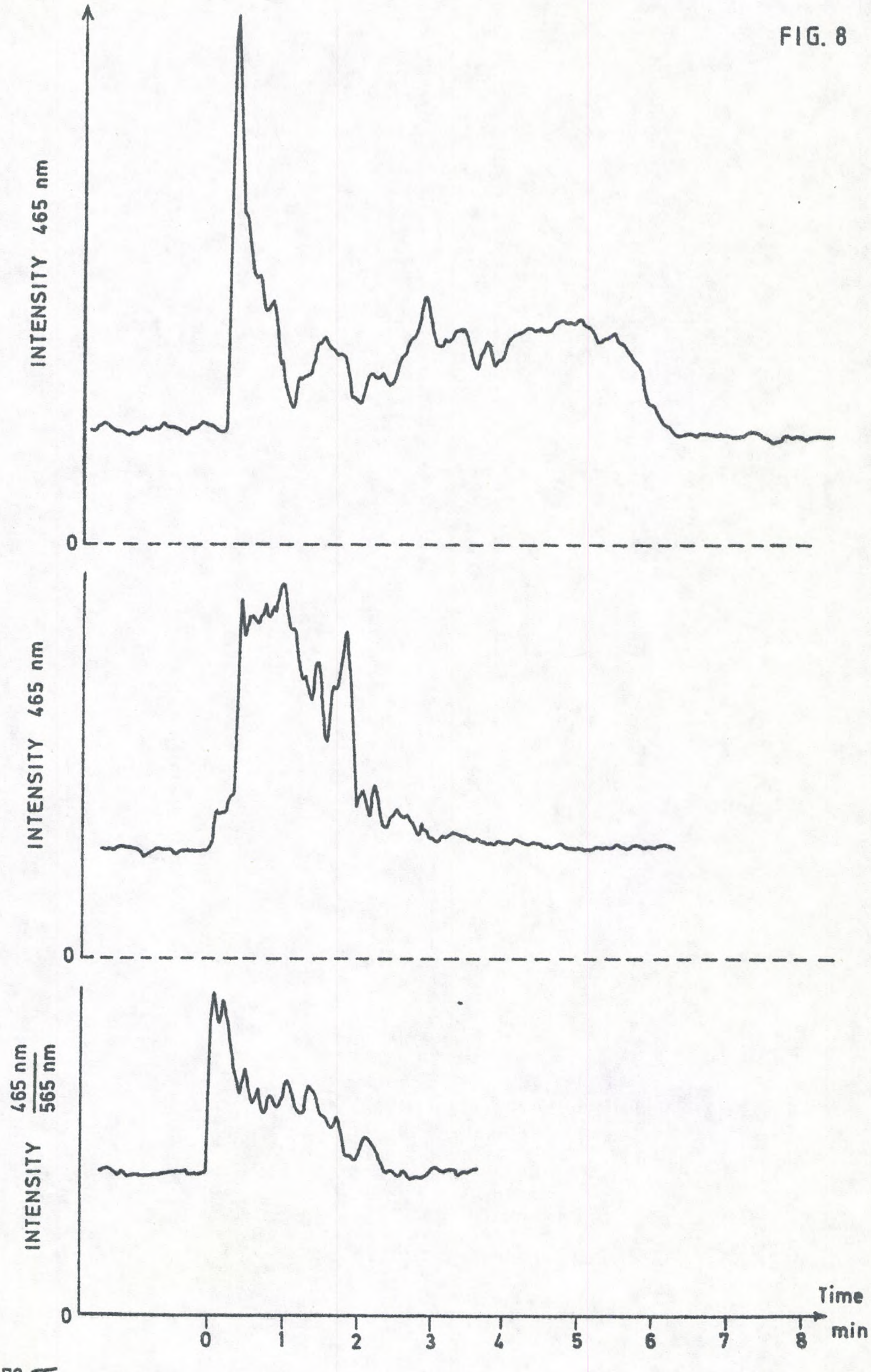
FIG. 8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0
INTENSITY 465 nm
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Time
min

HyA / 78 5

FIG. 9

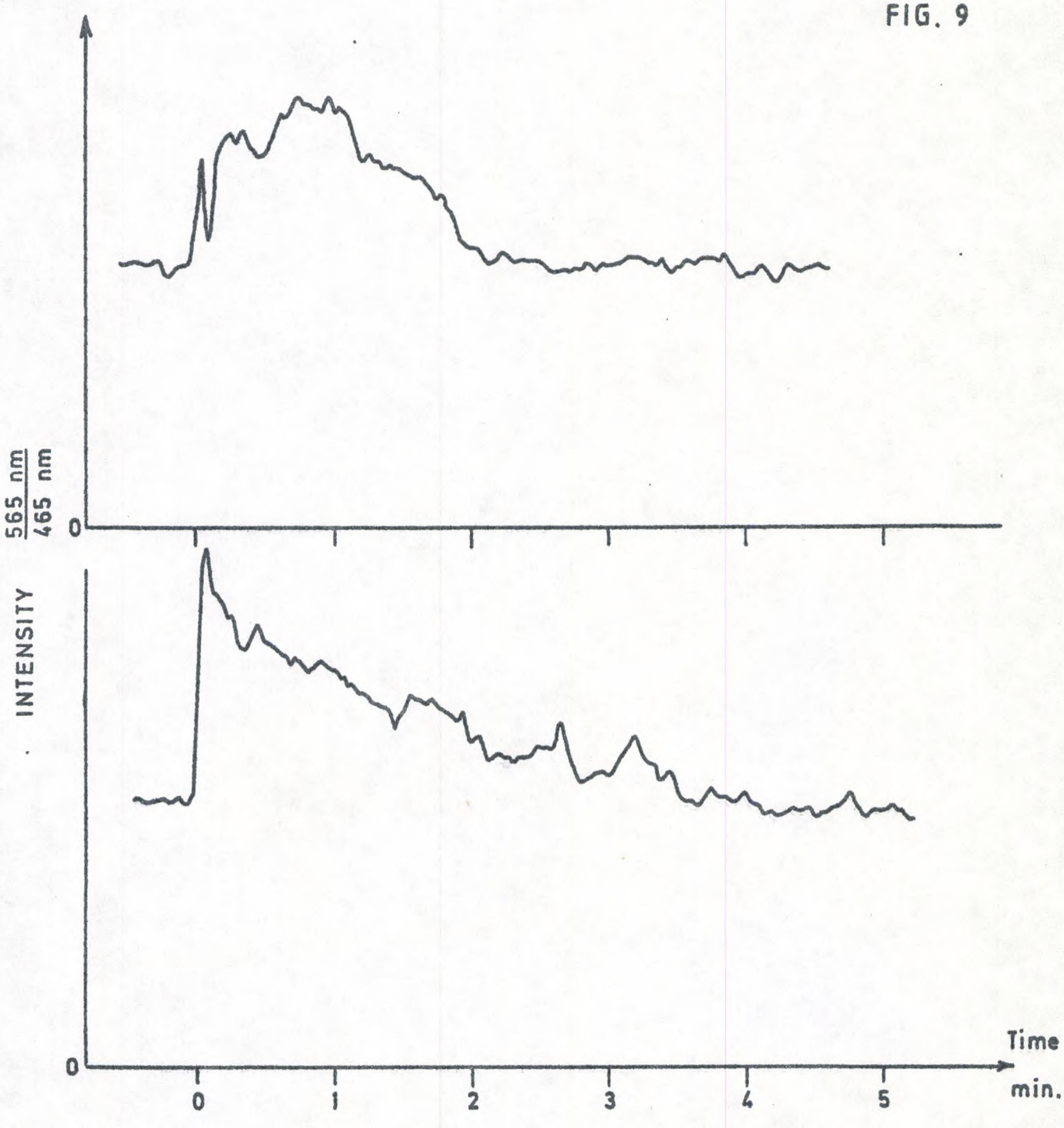
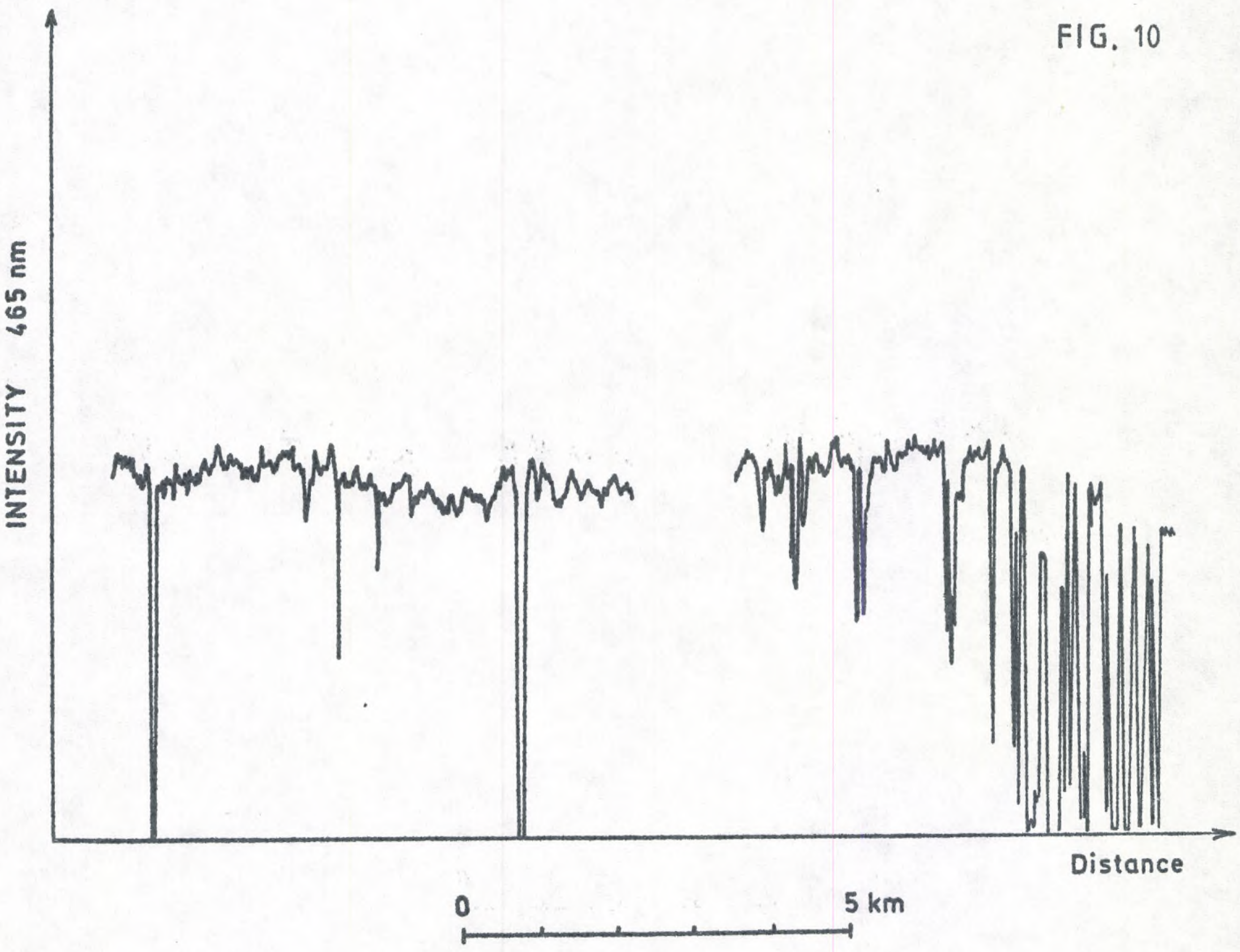


FIG. 10



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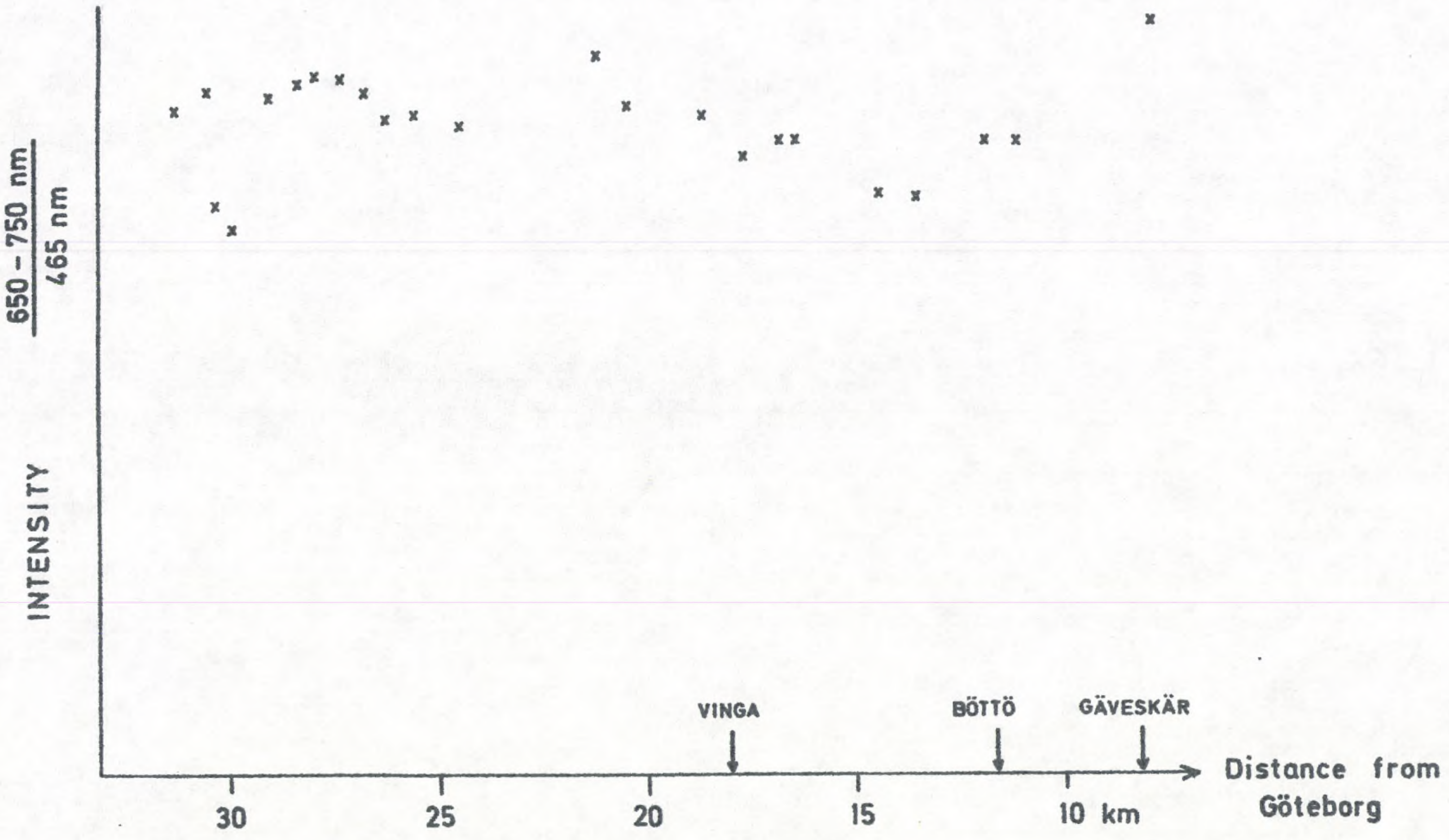

FIG. 11

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