Fast Photometry

M. J. Disney

A photon carries only four separate pieces of information: a direction, an energy, a polarization and a time of arrival in our detector. Of these four the easiest to measure is the last, and yet accurate timing has been, for reasons good and bad, sadly neglected. Nowadays, with relatively simple equipment, it is possible to do photometry with much higher timing precision than astronomers have generally used before. Nature so often provides surprises for those willing and able to push measurement into a new domain, that on grounds of principle alone fast photometry deserves much more of our attention.

It is a task of theory to stimulate experiment and yet, as in the case of rapid time-scale phenomena in astrophysics, it often acts in the contrary sense. It has been argued that since τ, the dynamical time-scale for gravitationally dominated bodies $\sim (G\varrho)^{-\frac{1}{2}}$ then τ (star) $\sim$ 1 hour and τ (galaxy) $\sim 10^7$ years, so that measurements on a time-scale of less than τ are a waste of time: probably this has something to do with neglect of the subject in the past.

Dr. M. Disney of the Royal Greenwich Observatory is currently visiting the ESO Scientific Group in Geneva. He has worked in Europe, the USA and Australia on a variety of problems in galactic and extragalactic astronomy. He is a codiscoverer of the only optical pulsar known, that in the Crab nebula. He is, however, together with his colleagues at the Anglo-Australian 3.9-metre telescope, in hot pursuit of other optical pulsars, and one may hope that it will not be long before more may be added to the list.

The 5-minute oscillations in the Sun were discovered only recently, while the rapid optical fluctuations in N galaxies, pulsars, BL Lacs and X-ray sources have been forced on our attention by observations made in non-optical regions of the spectrum. It is time we started to make systematic surveys of similar and related phenomena for ourselves.

The apparatus required can be as simple or as complex as one can afford. The basic requirements, besides the photometer, are an accumulator, a clock and an output device. Thanks to Planck the photons arrive in a handily digitized form (the important number to remember is that a 0^m star provides 1,000 photons sec^{-1} cm^{-2} $Å^{-1}$ band-pass in the visual at the Earth's surface), so the accumulator can be a fast counter which, at a signal from the clock, discharges its output onto a paper-type which can later be analysed. A much faster system can be constructed around a commercial stereo tape-recorder: the individual photoelectron pulses are amplified and recorded on one channel while timing pulses from the clock are recorded on the other. The data can afterwards be transformed to digital form, using a phase-locked loop or electronic flywheel to guard against dropping the odd timing pulse. The system is limited by the band-pass of the tape-recorder, and a better if more expensive approach is to write directly, or via a scaler, onto digital magnetic tape.

Whenever a minicomputer is available in the dome, a much more flexible real-time system can be built. If periodic variations are suspected, the signal can either be folded at some predetermined frequency (as in the case of radiopulsars of known period) or analysed for periodicity using a Fast Fourier Transform algorithm. Such a system was used (Fig. 1) to discover the first optical pulsar, NP 0532 in the Crab, with the 36" at Steward Observatory (Cocke, Disney and Taylor, *Nature,* **221,** 525, 1969). As minicomputers are becoming common user instruments in most domes, this is a system with a good deal of appeal.

For high-precision measurements, such as the search for very faint pulsars, where it is necessary to maintain timing accuracy of a millisecond or so over hours or even days, the clock needs a highly stable oscillator, and it may even be necessary to adjust it frequently by reference to one of the specially broadcast radio signals such as WWB. The adjustments that have to be made for Doppler effects due to the Earth's orbital und diurnal motion can be effected quite easily with the computer. The sensitivity of the system to poor photometric conditions can be radically reduced if a two-channel photometer is used with one channel on the programme star and the other monitoring some convenient star close by in the field.

As you might expect, there are pitfalls. Negative results are worthless unless the system has a demonstrated performance on known sources such as the Crab pulsar or DQ Her. Conversely, it is easy to pick up false signals from TV stations, ground loops and other sources of interference. And there are subtler effects. Strong pulsations were once detected from the nucleus of the Andromeda galaxy. Excitement was damped when it was afterwards found that the period corresponded exactly to one of the cogwheel periods in the telescope drive train. However, with a little care beforehand and a little caution afterwards most of those difficulties are overcome.

The real challenge in this subject, as in all observational astronomy, is not so much *how* to look but *where* to look. With so many possibilities open I hesitate to even suggest a strategy. Given sufficient time on a small telescope (≦ 20 cm) a random browse through the Yale catalogue might prove very rewarding. Such a project might appeal to the well-equipped amateur or the small professional observatory.

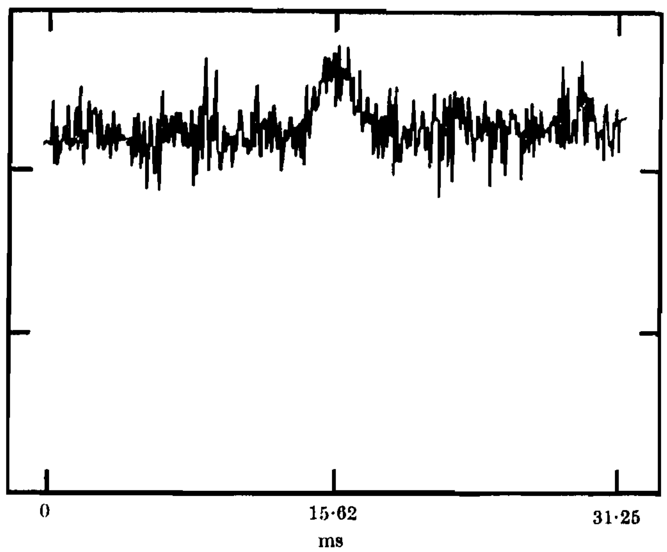

Fig. 1. — *The light-curve of the Crab pulsar as first seen in 1969. A minicomputer attached to a 36" telescope was used to fold the photon pulses in real time at the radio period of 33 milliseconds. Observers could watch the pulse appearing out of the noise on a cathode ray tube.*

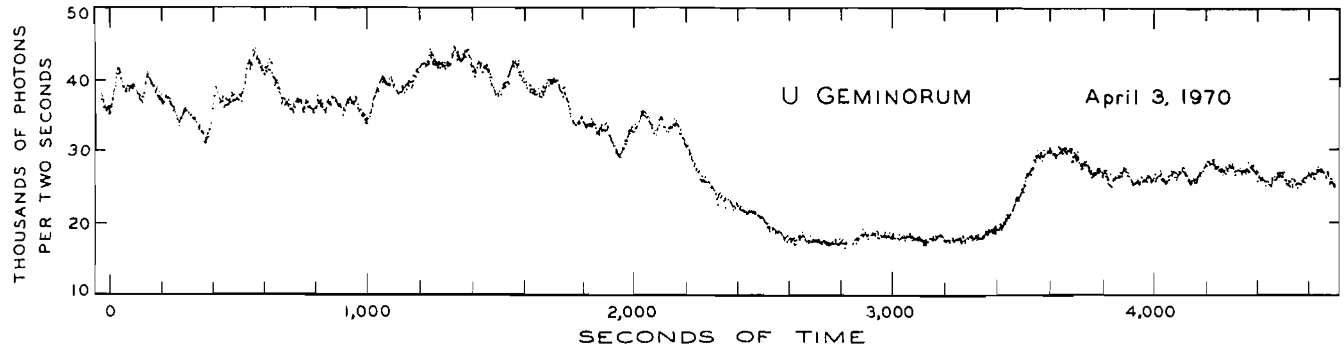

Fig. 2. — *The rapid flickering of the dwarf nova U Gem as measured by Warner and Nather. The flickering comes from a small spot where accreted material from a companion falls onto a white dwarf. Note that flickering stops during the eclipse.*

For the professional who must justify his observing requests on larger telescopes with at least some probability of success, one can pick four or five promising lines:

(a) Extragalactic pulsars: Radio pulses are smeared out or dispersed by electrons along the line of sight. This dispersion makes detection at great distances increasingly difficult and it may be impossible to *find* extragalactic pulsars in the radio without a prior knowledge of the period. Optical pulses are not dispersed and a survey of extragalactic supernovae might result in success. Previous observations suggest that a pulsar's optical luminosity falls off with a very high power ($\geqq 8$) of the period, and hence with the age. Young pulsars could therefore be very luminous and detectable out to tens of megaparsecs with a large telescope. The supernova envelopes will probably remain optically thick for some months after the explosion, so a guesstimate is necessary of the optimum time to search. The real goal is to measure the intergalactic electron density along the line of sight for, with a knowledge of the optical period, radio astronomers should then be able to detect the pulsar and measure its dispersion.

(b) Stellar black holes present an interesting challenge. Their time-scale $\tau \sim GM/c^3 \sim$ milliseconds. A 1-metre telescope should detect $\sim$ 400 photons/millisecond from a possible 10^m black hole, so the detection of the irregular fast flickering that should be a signature of these objects is possible. X-ray binaries like Cyg X-1 are a good place to start.

(c) If experience with Uhuru is anything to go by, the large expansion of X-ray astronomy which the HEOs will bring in the next years should provide a rich harvest for the fast photometrist. The accretion of gas onto degenerate stars ($\tau \sim 10$ to 10^{-3} sec) and black holes (10^{-3} to 10^{-4} sec) implies short-time-scale phenomena, and of course many sources, like the X-ray pulsar Her X-1, have proved to be equally active in the optical.

(d) Cataclysmic variables (novae) clearly display the accretion processes thought to be responsible for the X-ray binaries. In a beautiful series of observations (see Fig. 2) Warner and his colleagues (*Sky & Telescope*, **43**, 82, 1972) have unlocked many of the secrets of these systems, but much remains to be done.

(e) The fastest variations in the extraordinary objects in the nuclei of galaxies, BL Lacs and QSOs place very strong constraints on the physical processes involved (Elliot & Shapiro, 1974, Ap. J., 192, L3). The faster the variation the smaller the object. For a given size, virtually any model will have an upper luminosity limit, and by comparing prediction with observation, many models can be eliminated. In the case of BL Lacs, variations of a few per cent in times of minutes have been reported and there are tantalizing but unconfirmed hints that very fast (10 sec) 50 per cent bursts may occur. Of all the suggested models, only a black hole could accommodate these bursts.

Fast photometry has a short but interesting history and a very exciting future. For a modest cost, say $25,000, a transportable real-time system can be built to use with telescopes both large and small, and it is to be hoped that European astronometry will play an active role in these developments.

STAFF MOVEMENTS

Since the last issue of THE MESSENGER, the following staff movements have taken place:

ARRIVALS

Munich
None

Geneva
Marie Hélène Ulrich, French, astronomer

Chile
None

DEPARTURES

Munich
None

Geneva
Susanne Negre, German, administrative assistant

Chile
Marcel Moortgat, Belgian, technical assistant (mech.)

TRANSFERS

André Muller, Dutch, senior astronomer (from Munich to La Silla)

FELLOWS AND PAID ASSOCIATES

The following astronomers have taken up or will soon take up work as fellows or paid associates at the Scientific Group in Geneva:

Tenguiz Borchkhadze, Russian (Dec. 1, 1976–May 31, 1977)
Jan Lub, Dutch (from Jan. 1, 1977)
Per Olof Lindblad, Swedish (from Jan. 1, 1977)
Michel Disney, British (Jan. 15–April 15, 1977)
Jorge Melnick, Chilean (from March 1, 1977)
Sandro D'Odorico, Italian (March 15–May 15, 1977)
Piero Salinari, Italian (from April 1, 1977)