Optical Observations on Milli-, Micro-, and Nanosecond Timescales

D. Dravins, L. Lindegren, E. Mezey

Lund Observatory, Box 43, S-22100 Lund, Sweden

Abstract: Instrumentation and observing methods are developed for optical high-speed astrophysics, aiming at exploring milli-, micro-, and nanosecond variability. Such rapid fluctuations can be expected from instabilities in accretion flows, and in the fine structure of photon emission. For the optical, we have constructed a dedicated instrument, whose first version was tested on La Palma to study atmospheric scintillation on very short timescales. A second version is now under development, using photon-counting avalanche photodiodes as detectors.

1 The challenge of high-speed astrophysics

A goal is to explore the possible *very* rapid variability in astrophysical objects. Some processes may occur over scales of only kilometers or less, and there is no immediate hope for their spatial imaging. Insights could instead be gained through studies of their small-scale instabilities, such as hydrodynamic oscillations or magneto-hydrodynamic flares. Events which may be observable in the time domain include:

- Atmospheric intensity scintillation of stars on the shortest timescales
- Plasma instabilities and the fine structure in accretion flows onto white dwarfs and neutron stars
- Small-scale [magneto-]hydrodynamic instabilities in accretion disks around compact objects
- Radial oscillations in white dwarfs ($\simeq$ 100-1000 ms), and non-radial ones in neutron stars ($\leq$ 100 μs)
- Optical emission from millisecond pulsars ($\leq$ 10 ms)
- Fine structure in the emission ('photon showers') from pulsars and other compact objects
- Photo-hydrodynamic turbulence ('photon bubbles') in extremely luminous stars
- Stimulated emission, e.g. synchrotron radiation, from magnetic objects ('cosmic free-electron laser')
- Non-equilibrium photon statistics (i.e. non-Bose-Einstein distributions) from certain sources

https://doi.org/10.1017/S0252921100034849 Published online by Cambridge University Press

2 Optimum observing techniques

A number of criteria can be defined for optimizing an observing instrument, and we have designed such a unit, named *QVANTOS* ('Quantum-Optical Spectrometer'). Its first version was used on La Palma (Dravins et al. 1994; 1995). Design criteria included:

- *Data flow:* 1 ms resolution means 3.6 million points an hour, and 100 Mb in three nights. However, 1 μs gives 100 Gb, demanding real-time data analysis.
- *Faint sources:* To explore timescales shorter than typical intervals between successive photons, a statistical analysis of their arrival times is required.
- *The terrestrial atmosphere* causes rapid fluctuations of the source intensity, demanding an accurate calibration.
- *Efficient detectors:* New photon-counting detectors are emerging, e.g., silicon avalanche photodiodes are now being tested for a new instrument version.

Previous work shows that meeting all such requirements is non-trivial. The pioneering *MANIA* experiment (Beskin et al. 1982; 1994) has limitations in the maximum photon count rates that can be processed. Instruments in space avoid the atmosphere: the *High Speed Photometer* on the *Hubble Space Telescope* was a major effort (Bless 1982), but had limits on the amount of data that could be stored onboard. Our instrument also has limits in the sense that the full data stream is not saved, only certain statistical functions.

2.1 The role of very large telescopes

The new generation of very large optical telescopes will permit enormously more sensitive searches for rapid phenomena. On submillisecond timescales, data rates become very high and light curves are of little use. Measurements instead have to be of power spectra or other statistical functions, which increase with the light collected to a power of 2 or more, making the gains very much greater than in ordinary photometry or spectroscopy (Dravins 1994).

References

Beskin G.M., Neizvestnyi S.I., Pimonov A.A., Plakhotnichenko V.L., Shvartsman V.F., 1982, in C.M. Humphries, ed. *Instrumentation for Astronomy with Large Optical Telescopes*, IAU Coll. 67, Reidel, Dordrecht, p. 181

Beskin G., Neizvestny S., Plokhotnichenko V., Popova M., Zhuravkov A., Benvenuto O.G., Feinstein C., Méndez M., 1994, A&A 289, 141

Bless R.C., 1982, in D.N.B. Hall, ed. *The Space Telescope Observatory*, NASA CP-2244, p. 106

Dravins D., 1994, ESO Messenger No. 78, (in press)

Dravins D., Hagerbo H.O., Lindegren L., Mezey E., Nilsson B., 1994, in Instrumentation in Astronomy VIII, D.L. Crawford & E.R. Craine (eds.), SPIE 2198, p. 289

Dravins D., Lindegren L., Mezey E., Young A.T., 1995, Appl. Opt., (to be submitted)