11.1: Introduction to Photographic Astrometry

Astrometry is the art and science of measuring positions of celestial objects, and indeed the first step in determining the orbit of a new asteroid or comet is to obtain a set of good astrometric positions. For much of the twentieth century, most astrometric positions were determined photographically, although transit circle measurements were (and still are in some applications) important. A photographic plate or film would be baked for several hours in an oven in an atmosphere of dry hydrogen and nitrogen. This "hypersensitization" was known to increase the sensitivity of the emulsion in long exposures. The film would then be exposed through a telescope to an area of the sky containing the asteroid. An hour or so later, a second photograph would be exposed, the asteroid presumably having moved slightly between the exposures. Exposure times would be from several minutes to an hour or even more, and the telescope had to be carefully guided throughout the long exposure. After exposure, the film had to be developed in a chemical solution in a dark-room, then "fixed" in another solution, washed under running water, and hung up to dry. After these procedures, which took some hours, preparation for measurement could start. The first thing to do would be to identify the asteroid. (In Mrs Beecham's words, "First catch your hare".) To do this, the two photographs would be viewed rapidly one after the other with a blink comparator (in which case the asteroid would move to and fro) or viewed simultaneously with a stereocomparator (in which case the asteroid would appear to be suspended in air above the film). Next, a number of comparison stars would have to be identified. This would be done by consulting a star catalogue and laboriously plotting the positions of the stars on a sheet of paper and comparing the pattern with what was seen on the photographs.

Each photograph would then be placed in a "measuring engine", or two-coordinate measuring microscope, and the x- and y-coordinates of the stars and the asteroid would be measured. Tedious calculations would be performed to convert the measurements to right ascension and declination. The results of this process, which would typically take several hours, would then be sent by mail to the Minor Planet Center of the International Astronomical Union in Cambridge, Massachusetts.

Starting in the early 1990s, photographic astrometry started to be superseded by CCD (charge coupled device) astrometry, and today almost no astrometry is done photographically, the CCD having taken over more or less completely. Everyone knows that the quantum efficiency of a CCD is far superior to that of a photographic emulsion, so that one can now image much fainter asteroids and with much shorter exposures. But that is only the beginning of the story – the CCD and other modern technologies have completely changed the way in which astrometry is carried out. For example, vast catalogues containing the positions of hundreds of millions of faint stars are stored in computer files, and the computer can automatically compare the positions of the stars in its catalogue with the star images on the CCD; thus the hitherto laborious process of identifying the comparison stars is carried out automatically and almost instantaneously. Further, there is no measurement to be done – each stellar image is already sitting on a particular pixel (or group of pixels), and all that has to be done is to read which pixels contain the stellar images. The positional measurements are all inherently completed as soon as the CCD is exposed. The positional measurements (of dozens of stars rather than a mere half-dozen) can then be automatically transferred into a computer program that carries out the necessary trigonometrical calculations to convert them to right ascension and declination, and the results can then be automatically sent by electronic mail to the Minor Planet Center. The entire process, which formerly took many hours, can now be done in less than a minute, to much higher precision than formerly, and for much fainter objects.

Why, then, would you ever want to read a chapter on photographic astrometry? Well, perhaps you won't. After all, to convert your observations to right ascension and declination today, a single key on your computer keyboard will do it all. But this is because someone, somewhere, and usually a very anonymous person, has written for you a highly efficient computer program that carries out all the necessary calculations, so that you can do useful astrometry even if you don't know the difference between a sine and a cosine. Thus you can probably safely bypass this chapter.

However, for those who wish to plod through it, this chapter describes how to convert the positional measurements on a photographic film (or on a CCD) to right ascension and declination – a process that is carried out by modern computer software, even if you are unaware of it. Much of this chapter is based on an article by the author published in the *Journal of the Royal Astronomical Society of Canada* $\mathbf{76}$, 97 (1982), and you may want to consult that in the hope that I might have made it clear in either one place or the other.