# What Gaia ‘sees’

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## Introduction

Stars captured in Gaia images don’t appear as points of light: rather, they form an extended cross-like shape with twin arms extending in opposite directions, and a lot of fainter structure only detectable for bright stars (see figure 1). This is known as the **Point Spread Function** (PSF), and it is a consequence of the elaborate system of ten mirrors used to collect and focus the star light onto Gaia’s 106 detectors.

Over the course of the mission, the PSF gradually evolves in response to changes in the focus of the telescope, the build up of ice on the mirrors, temperature variations, damage to the detectors caused by cosmic radiation, and a variety of other effects. Part of the work carried out in Edinburgh involves tracking these changes and the effect that they have on the scientific quality of the data.

## Measuring the positions of stars

At a very basic level, Gaia relies on the **precise measurement of the positions of stars in a digital image**. In order to make the most accurate measurements, it’s necessary to map out the PSF and build a template that we can use to fit to the observed star images. The template must account for, among other things, the colour of the star, which has a large effect on the shape of the PSF.

It is actually a great advantage that the images of stars are spread out (rather than forming a single bright pixel), as the gradual decrease in brightness in the wings of the profile provides good constraint on the position of the star within a single pixel. A lot of work has been carried out in Edinburgh to map out Gaia’s PSF, with the result that we are able to measure the positions of many stars to within less than one hundredth of a pixel. Over the course of the five-year mission about seventy such measurements are made for every star, which are combined to obtain extremely accurate estimates of the star position and motion over time.

## Ten mirrors and one billion pixels

Gaia uses a combination of **ten flat and curved mirrors** to collect, reflect, focus and merge the light from two directions simultaneously onto a single large array of detectors. The mirrors are mounted on a rigid doughnut of silicon carbide about two metres across (see figure 2) that ensures the mechanical stability of the optical system. Each mirror is made of polished silicon carbide coated with a thin reflective layer of silver, and has been meticulously smoothed to within ten millionths of a metre. Construction of the mirrors was carried out by a number of European companies in France, Germany and Belgium.

Gaia’s camera consists of 106 individual detectors that altogether have around one billion pixels. Each of the 550 million pixels in Gaia’s main astrometric instrument is ten microns in size (0.01 millimetres) and sees about 59 milliarcseconds (0.000016 degrees) of the sky. The detectors were designed and built by UK-based company e2v and are among the most complex ever manufactured.

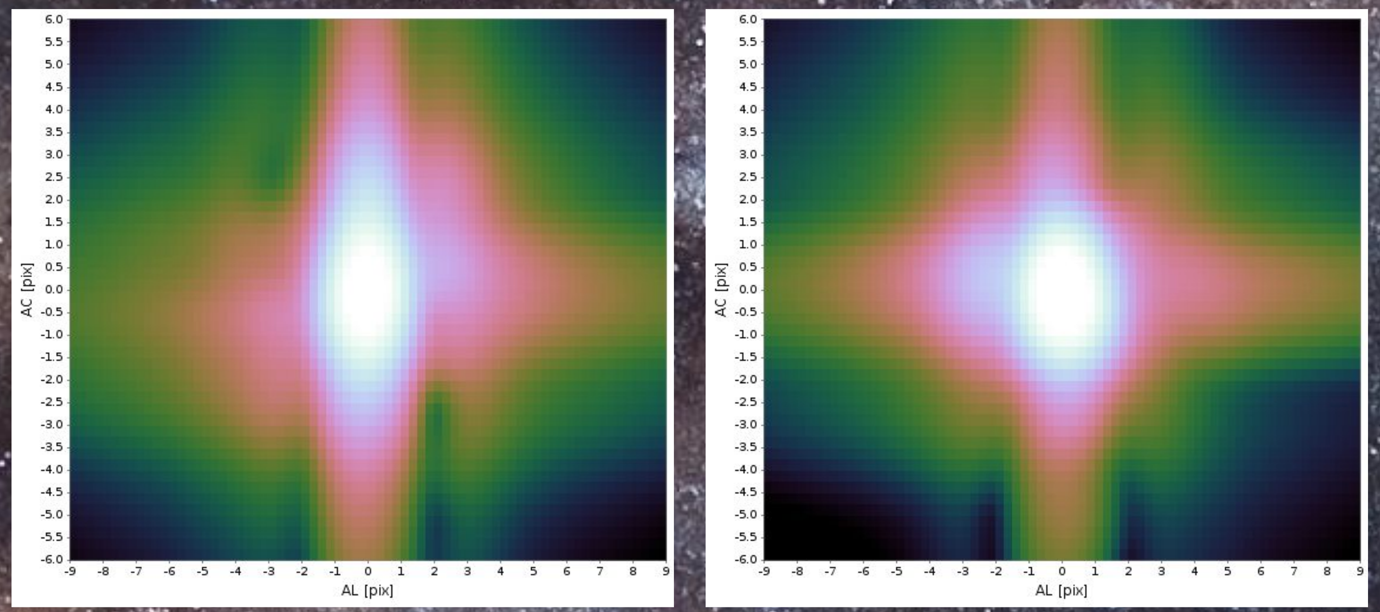



*Figure 1: The Point Spread Function (PSF) for each of Gaia’s two telescopes; accurately mapping the PSF is key to making precise measurements of the positions of stars*

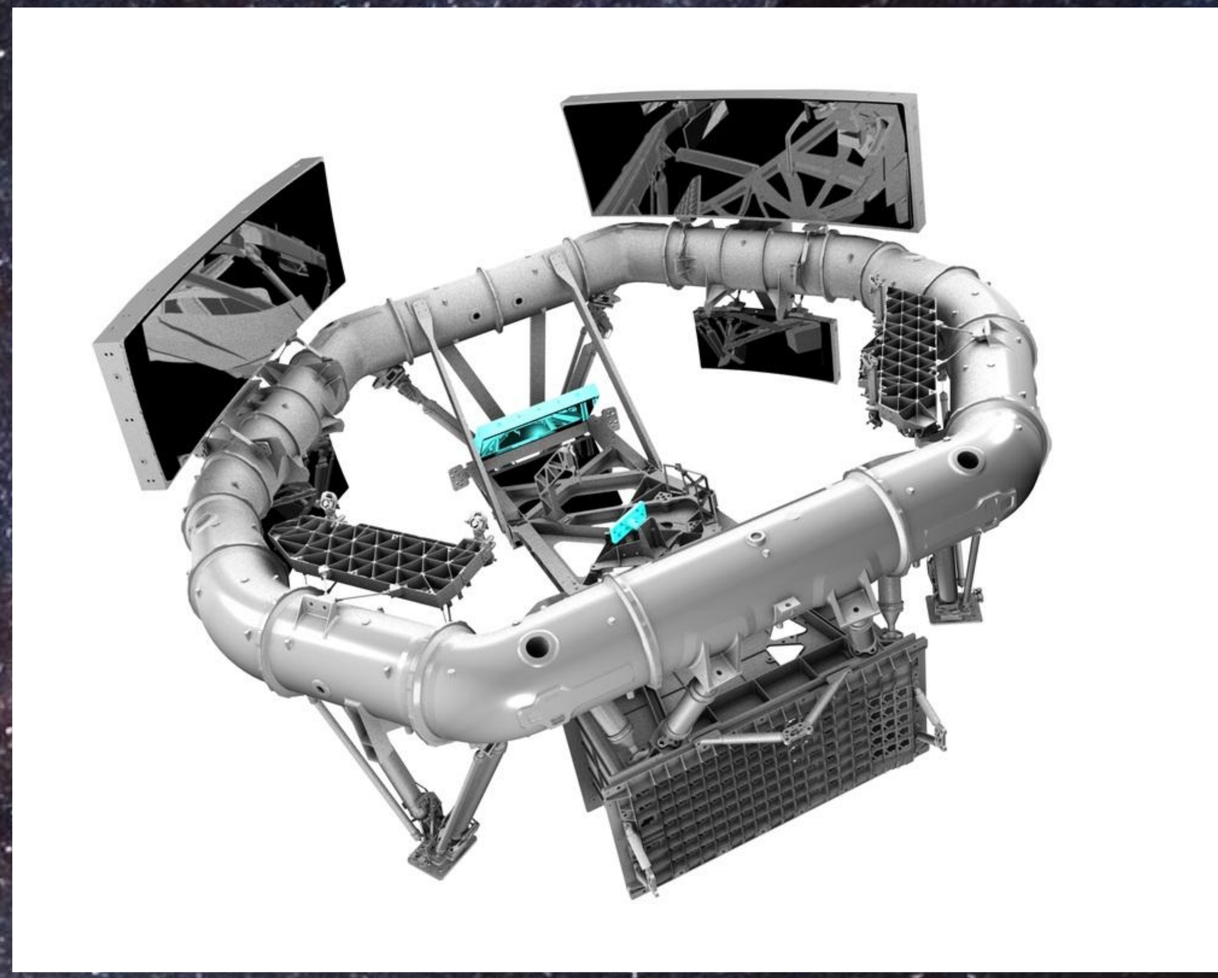
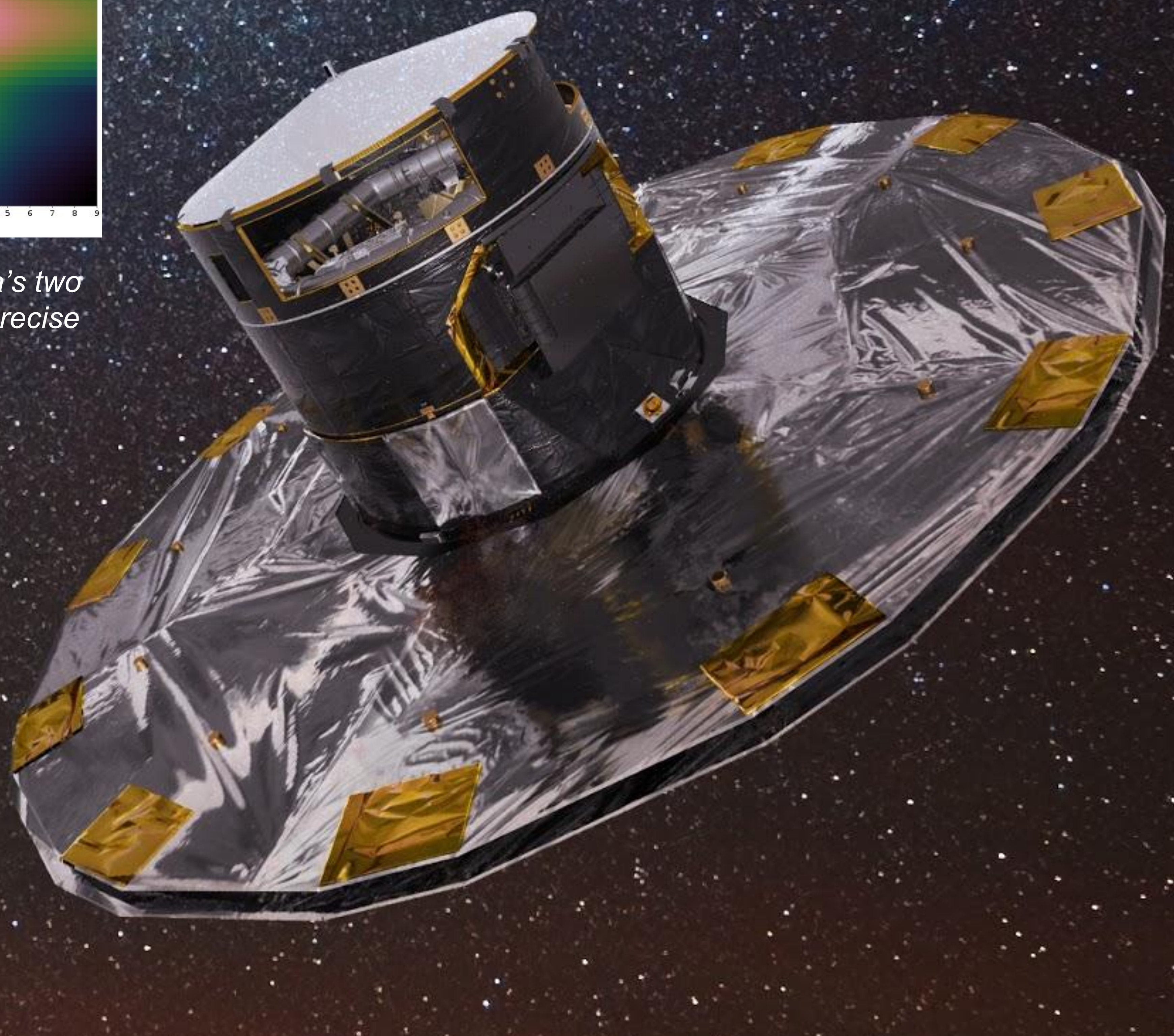


*Figure 2: Gaia’s optical system consists of ten mirrors mounted on a silicon carbide torus that collect and focus light onto Gaia’s 106 detectors*

## The technical bit ...

The shape of the images of stars as seen by Gaia is a consequence of Gaia’s complex ten-mirror optical system. Some features of this will be familiar to anybody with an interest in photography; others are unique to Gaia.

- Gaia’s stars appear cross-like due to diffraction of the light by the rectangular entrance pupil and mirrors: the cross shape is the diffraction pattern of a rectangular pupil. Analogously, in a standard digital camera the images of bright lights may appear as six-pointed stars because this is the diffraction pattern of the hexagonal entrance pupil usually found in cameras with adjustable apertures.
- The shape of the image of a star viewed through a telescope is called the *Point Spread Function* (PSF) and is a characteristic of the optical system - it is similar in concept to the *Impulse Response* for other types of measuring instrument. Producing a small PSF was one of the design requirements of Gaia’s ten-mirror optical system.
- The combination of three curved mirrors used in each of Gaia’s two telescopes is called a *Three-Mirror Anastigmat*. This is a clever design that reduces the main optical aberrations, enabling a much wider field of view than designs that use just one or two curved mirrors.
- Gaia’s astrometric instrument uses a broad band filter to capture as much light as possible and detect faint sources. This results in a strong colour variation in the PSF due to wavelength-dependent diffraction effects, which must be measured and calibrated.



**Gaia Artist's impression - credits: ESA/ATG medialab; background image: ESO/S. Brunier**