Detectors

1. Basics & Nomenclature

Modern astronomical detectors come in several varieties depending on wavelength and use case. The traditional detector introduced in the 1800s, the photographic plate, is too inefficient ($\sim 5\%$) and too inconvenient to convert into digital form to be of use today, though it continued to be used until about 2000. Here, we will not review the physics behind modern detectors except insofar as necessary to explain how to interpret data taken with them.

In the optical, out to about a micron, the most common detector in use is the *charge-coupled device* (CCD). Out to about 28 μm, the most common detectors are infrared detector arrays. Although CCD and infrared arrays are different technologies, both are semiconductor-based detectors that detect photons of energy higher than their band gap between their bound valence electron energies and their conduction band. Silicon is the best-developed CCD technology and has a band gap of 1.1 μm. Germanium CCDs could in principle extend this sensitivity to 1.8 μm, but their technology is not cost-effective today. HgCdTe ("MER-CAH-TEL") infrared detectors have a band gap of that can be designed anywhere between 0.4–12 μm. Si:As detectors can extend to 28 μm. **check what WISE is**.

Each pixel of a CCD detects individual photons that hit it, each of which usually contributes one electron to the overall signal. For most hardware, the charge is "read out" at amplifiers along the side of the CCD, by transferring the charge from pixel to pixel to the edge of the CCD. At the last pixel the charge is converted to a digital signal by the amplifiers. CCDs may be readout by various numbers of amplifiers. Because of the finite temperature of the devices, some number of electrons are released even when there are no photons entering the device; this phenomenon is known as the *dark current*. To reduce the dark current, CCD detectors need to be cooled; variations in temperature can cause variations in the dark current.

Infrared detector arrays operate similarly, but the infrared-sensitive materials cannot today be used to support the circuits necessary for CCD operation. Insted, the infrared sensitive material is bonded to a silicon detector on which the read out occurs. These detectors are not CCDs but multiplexers, which are read directly out on each pixel. The charge can be read out nondestructively, allowing many reads on the same pixel. However, the read out is intrinsically noisier.

From this basic understanding, there results an interpretation of the digital numbers reported by a semiconductor device:

$$\mathrm{DN} = \mathrm{Gain}\ n_e = \mathrm{Gain}\ \ [\times n_p + \mathrm{Dark}] \tag{1}$$

where n_e is the number of electrons recorded by the device, n_p is the number of photons actually detected, i.e. which are converted to electrons (which will include all background photon sources),

"Gain" represents the conversion of photons to the DN reported by the electronics, and "Dark" represents the dark current in units.

The noise in the DN is due primarily to two sources: Poisson noise around the mean n_e and *read noise* associated with the electronics. The read noise does not usually depend on the signal. Therefore:

$$\sigma_{\rm DN}^2 = {\rm Gain}^2 n_e + {\rm Read\ Noise}^2 \tag{2}$$

The Poisson noise includes the "object" signal, the background signal, and the dark current contributions to the expected number of electrons n_e.

Over their usuable dynamic range in number of electrons, CCD devices are remarkably but not perfectly linear. CCD devices are limited in their dynamic range by the number of electrons each pixel can store. If the number of electron approaches or exceed this limit, those electrons typically bleed to neighboring pixels; since the electronics is not isotropic, they typically bleed along the same direction the device is read out. They also may be limited by the dynamic range of their analog-to-digital converter, which is often 16-bits.

CCDs are also sensitive to cosmic rays and these will release electrons that contribute to the signal. A characteristic feature of a cosmic ray is that it will be a sharper feature than the atmosphere and optics allow. The exact nature of the cosmic ray distribution depends on altitude (with more reaching higher altitude and space detectors) and orientation of the detector relative to vertical (since underneath the atmosphere the cosmic rays will be directed preferentially downwards).

In the ultraviolet, other detectors are still in use. For example, GALEX uses a position dependent proportional counter. These devices are essentially a crossed grid of wires under voltage inside a chamber filled with an inert gas that can be ionized by UV photons. When a UV photon causes a charge track, the voltage change is detected and recorded. Unlike CCDs, these detectors can detect individual photons.

In the X-rays, CCD detectors are now used. CCDs lose sensitivity in the UV due to absorption on their surfaces, but at energies > 120 eV (< 100 Å) they are sensitive again. Unlike in the UV and optical, X-ray photons can release many electrons. This fact, and that the photons much rarer, allows X-ray CCDs to be energy sensitive. At high count rates, they become complicated to analyze due to .

2. Commentary

We will discuss spectra later.

3. Key References

- *Design and Construction of Large Telescopes*, **?**
- *Kitchin*

Gunn et al. (2006)

4. Order-of-magnitude Exercises

1. Typical read noise in IR arrays vs optical and sampling
2. X-ray background

5. Analytic Exercises

1. Noise as a function of object and background
2. Bias in estimating noise from data

6. Numerics and Data Exercises

1. Sky brightness vs airmass during SDSS drift scan
2. OH variations during SDSS drift scan
3. Plot sky spectrum vs moon phase from SDSS
4. OH variations across SDSS fields
5. Find extreme airmass SDSS images, see refraction

REFERENCES

Gunn, J. E., et al. 2006, AJ, 131, 2332

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