Science & Technology Facilities Council
UK Astronomy Technology Centre

Astronomy detectors

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Introduction and contents

- General overview of astronomy detectors, mainly visible, IR, sub-mm
  - Radio is a different, larger, problem
- Not ground or space based specifically
- Contents;
  - Detector types: CCDs, IR arrays, QWIPs, KIDS….
  - Speed issues related to detection
  - Speed issues related to use

Detector types

- Photo-electric
  Photons release bound charge carriers
- Thermal
  Absorbed photons raise the temperature
- Coherent
  The electric field of the photons is coupled

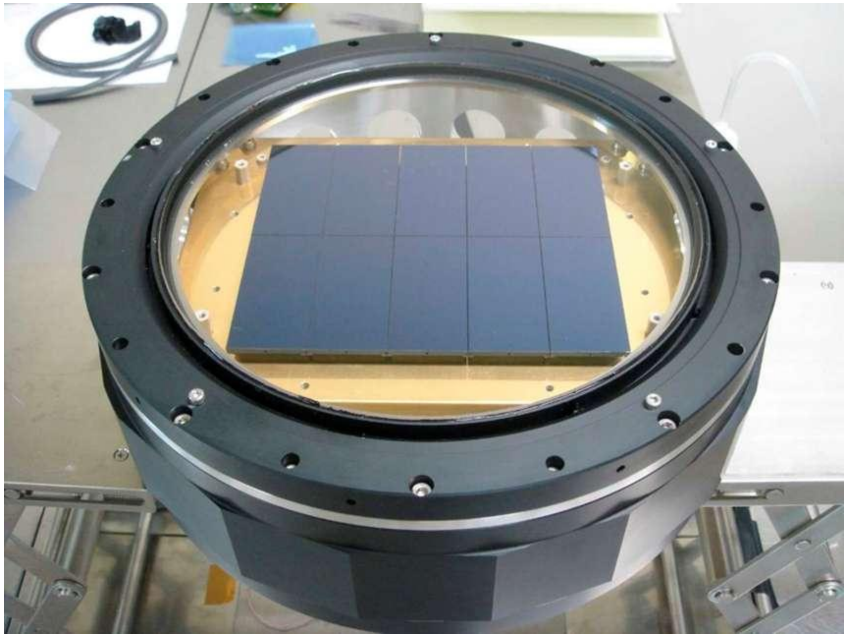
- CCD
- Photodiode arrays
  - QWIPs
  - QDIPs
- Bolometer arrays
  - Micro-bolometers (resistance)
  - Transition edge sensors
- KIDS

CCDs

- Modern CCDs: high QE, high full well, low dark noise, low read noise
- Read noise $\propto$ Speed, but speed already more than high enough for imaging, spectroscopy;
  - High full well & low dark current means long integrations (hours)
  - More pixels means mosaic arrays, not bigger ones
- No pixel processing: Correlated Double Sampling (CDS) done on controller
- X-ray astronomy has higher rates, but correspondingly higher signal

CCD array typical characteristics

- Size 2Kx4K pixels (non-butable are bigger)
- 2 bytes/pixel
- 10 second read (CDS)
- 1.6 MBytes/s (per array)
- 10 array mosaic = 16MBytes/s
- Little or no on-line processing



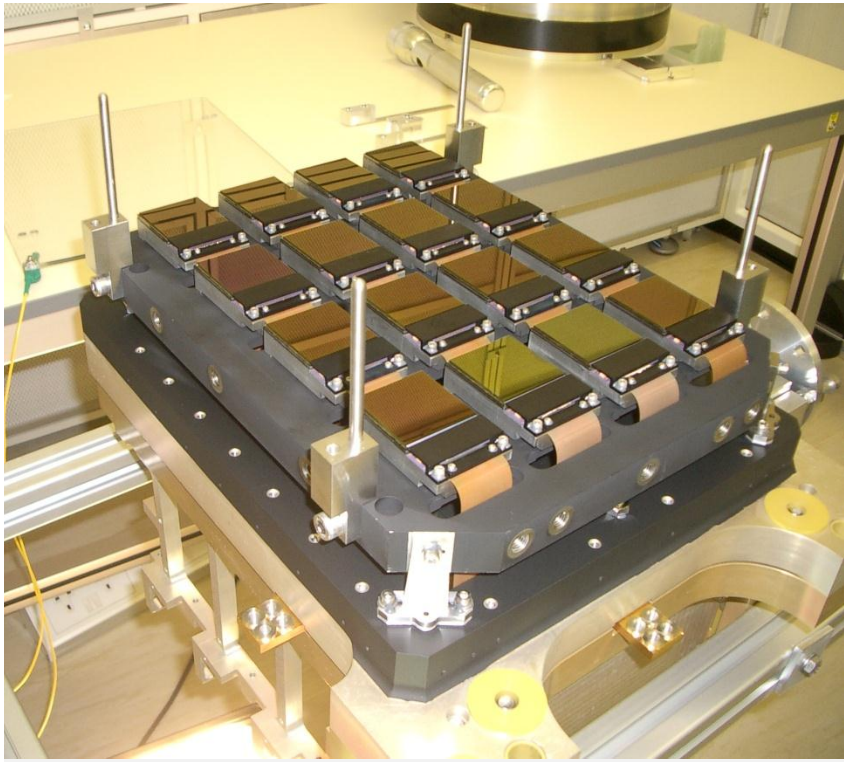
Subaru SuPrime Camera: 10 2Kx4K Hamamatsu CCDs

IR arrays

- Much higher rates than CCDs;
  - Background gets higher as wavelength gets longer
  - Arrays have lower full well depth
  - Non-destructive reads (NDR) provide noise reduction
- Multiple fast channels
  - If the trend continues, then some speed issues, but only at 100 - 1000 MBytes/s
- (but again bigger detection area means mosaics, not bigger arrays)

IR photodiode array typical characteristics

- Size 2Kx2K pixels (4Kx4K in the works)
- 2 bytes/pixel
- 1 second read (NDR)
- 8 MBytes/s (per array)
- 16 array mosaic = 128MBytes/s
- Needs “simple” statistical fit to NDR data



VISTA Camera: 16 2Kx2K IR arrays

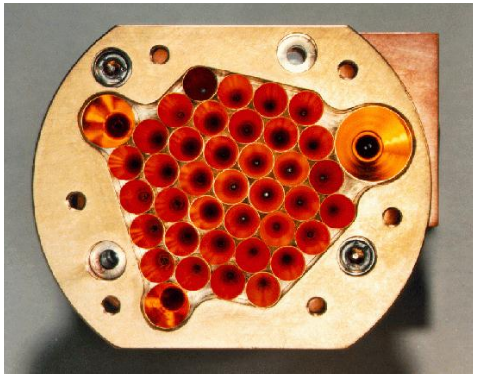
QWIPs - Quantum Well Devices

- Cheaper to manufacture than diode arrays
- Wide wavelength range
- Broad band energy resolution possible
- Best at longer wavelengths (>5µm) due to noise characteristics
- With energy resolution produces >100 Mbytes/s

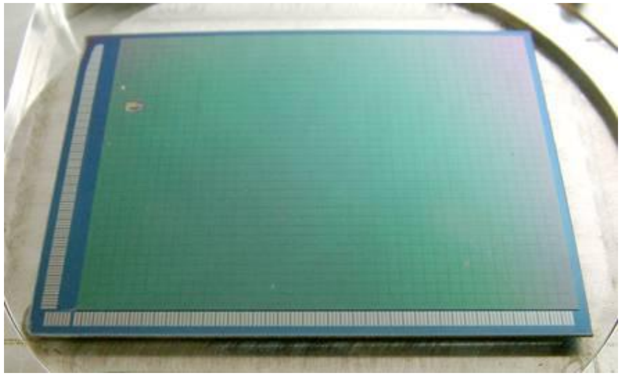
8-12 µm IR image taken with NASA 1 megapixel GaAs QWIP

Bolometer arrays

- Microbolometers (resistive) have too much noise
- Modern transition edge sensor systems limited by readout speeds
- Readout speed is set by background & effective full well, typically one to a few photons
- At their max. size; the problem is connectivity, not data rate…..



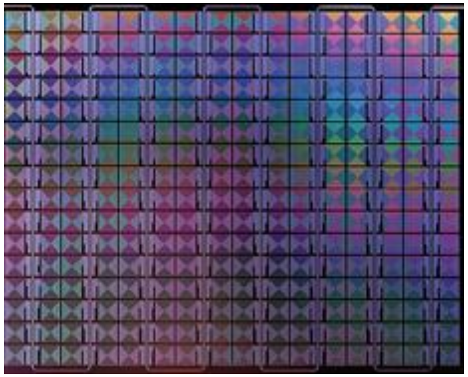
SCUBA LW feed-horn array



SCUBA-2 TES array

KIDs - Kinetic Inductance Devices

- Photon absorbance increases inductance
- Inductance causes change in resonant frequency of microwave resonator



Titanium nitride Microwave KID

- Freq. division multiplexing allows many pixels to be read over a single broadband microwave channel.
- 100MBytes/s to 1GBytes/s and rising….

Current observational speed issues

- Ever bigger data sets: desire to reduce data on-line: ALMA, wide field surveys
- Observation by SNR measurement (as opposed to estimation) for time efficiency
  - Also fast science turnaround for the same reason
- Statistical processes: Energy resolving detectors, charge amplification etc
- Fast triggering for transient events (SN, GRBs, X-Ray flares etc)

Future speed issues

- Biggest speed issues relate to specific uses
  - Adaptive Optics
  - Optical Interferometry (i.e. Amplitude)
  - Intensity Interferometry
  - Very wide field surveys
  - Planets (!)
- Note that for most of these it's the latency that's the biggest issue, as opposed to the absolute throughput

Adaptive Optics

- Next gen telescopes reliant on AO
- 1000 actuators/mirror
- Many deformable mirrors (MCAO)
- Tomographic reconstruction, ensemble Kalman filters
- c.f. 100x100 sparse matrix inversion @ 100Hz, say 1-10 Tflops

Interferometry

- Existing optical interferometry
- Fringe phase and contrast estimation
- ABCD estimator, group delay estimation
- Phase “speed” estimation
- ~1 Tflop ?

Intensity Interferometry

- Requires GHz sampling rates
- 10s of baselines, so 1000s of correlations
- Relatively cheap optical systems
- Piggybacks on SKA developments
- UK interest?

Very wide field surveys

- Surveys get ever bigger
- VISTA 200-300 GB per night
- Expect large spectrographics surveys next
- 1TB/night ?

Planet searches

- Very high spatial resolution
  - Space based interferometry, coronography
  - Probably longer wavelengths
- Very high temporal resolution
  - Objects of opportunity (how many?)
  - Low SNR: differential imaging?
  - Very fast detectors, possibly time resolving
    - LLL CCDs
    - SPADS
    - KIDs

So, what's important? My guess is

- Speed isn't as big an issue as in particle physics
- Biggest problem is probably latency → I/O
- Small, low latency front end processing
- Big, non-real-time data processing
- The big enablers;
  - Faster, lower latency I/O (Direct to CPU, optical?)
  - Multi core, embedded, CPUs (Stream processing)
  - Common architecture
  - Better long term support (Obsolescence)