"THE ONLY UNIFORM DETECTOR IS A DEAD ONE"

- Bias frames – zero-point, fixed pattern, overscans, trimming

- Dark current – temperature sensitivity, cosmic ray characterisation

- Flat fields – pixel-to-pixel, large scale, dust...., dome flats, twilight sky flats, superflats from targets

- Illumination correction – scattered light in flats causes residual spatial sensitivity variations

- Fringing – wavelength, spatial and temporal dependence
  = problem only in the R, I, i' and z passbands

- Cosmic rays – how to remove ? ignore ?

- NIR sky correction – sky is both spatially and temporally variable in NIR requires extra estimation and correction step cf. to optical

- Other problems – hot spots, traps, dead pixels/columns, saturation, video pattern noise, CTE and smearing, deferred charge field distortion, cross-talk

- Combining frames – common theme above and for targets too

STAGES IN CCD DATA PROCESSING

Following Gullixson:

$$raw = (obj + sky \times (1 + fringe)) \times qe + dark + flash - skim + bias$$

Correction for Zero exposure Additive Spatial Systematics

$$< dark >= dark + flash - skim + bias$$

$$< skim >= flash - skim + bias$$

$$< bias >= bias$$

overscan region to monitor and remove variations in bias DC level.

$$raw- < .... > -(ovscn- < ovscn >) = (obj + sky \times (1 + fringe)) \times qe$$

Correction for Multiplicative Spatial Systematics – flat fielding

$$< flat >= qe + dark + flash - skim + bias$$

$$const \times \frac{raw- < .... >}{< flat > - < .... >} = obj + sky \times (1 + fringe)$$

Correction for Additive Spatial Systematics – shift and stare

$$< sky >= sky \times (1 + fringe)$$

Register individual frames (–geometric distortion) and Combine

$$x' = a.x + b.y + c; \quad y' = d.x + e.y + f$$

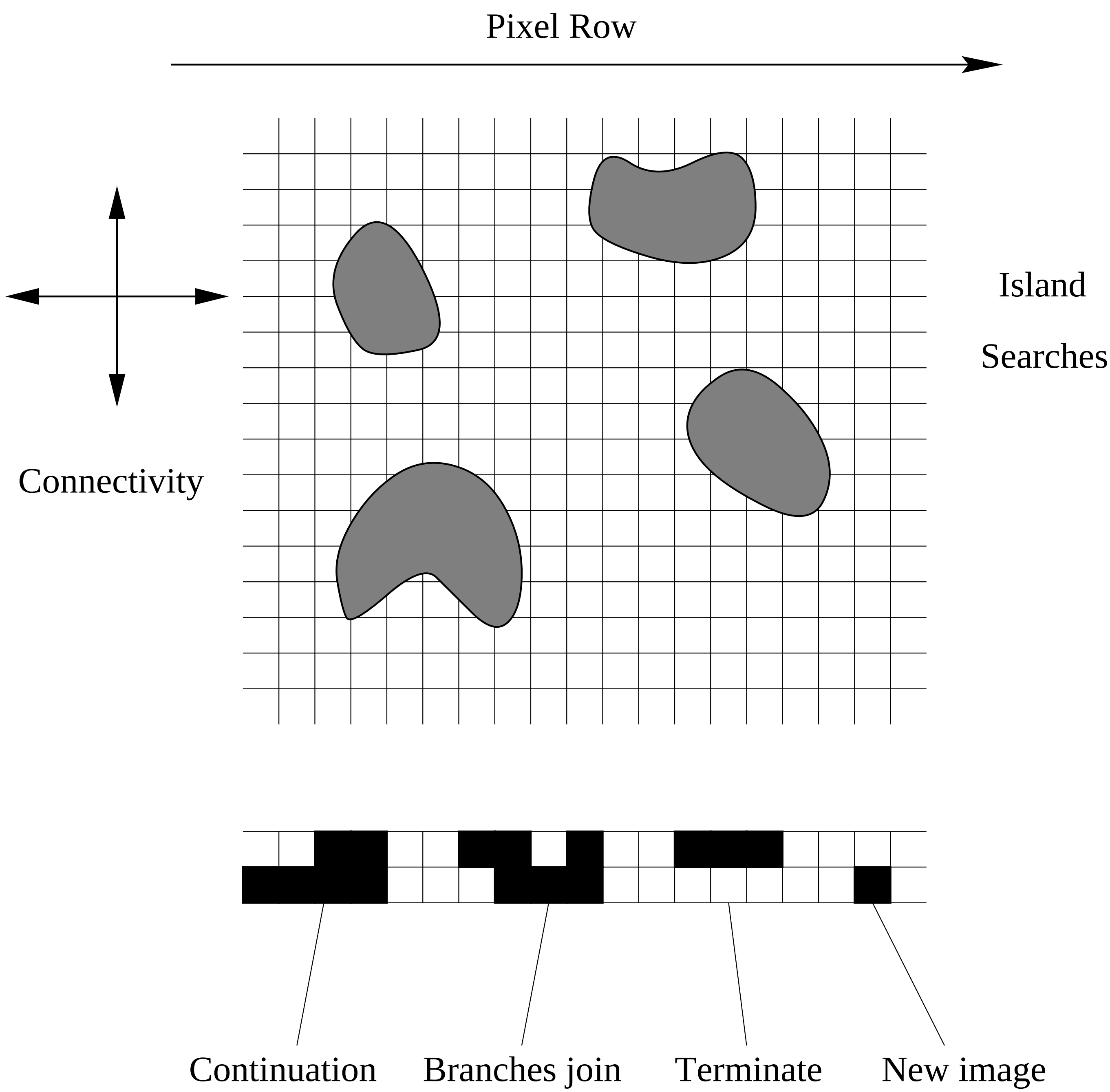
IMAGE DETECTION AND PARAMETERISATION

SKY ESTIMATION

- partition the field into background regions
- build up the 2d array of background values
- or use annulus around chosen image
- random error is roughly $\sigma_{sky}/\sqrt{N_{sky\ pix}}$

  size chosen as compromise between small enough to follow variation in the background, but large enough to give a small error on the background
- form the histogram of pixel values in the region
  - mean is badly biased
  - median is better but still biased
  - fit a Gaussian to the central peak – better still
  - model the skewness (Bijaoui 1980) – stability ?
- NIR - much more difficult for several reasons – principle is the same
- sky varies a lot more on short time-scales → need sky subtraction

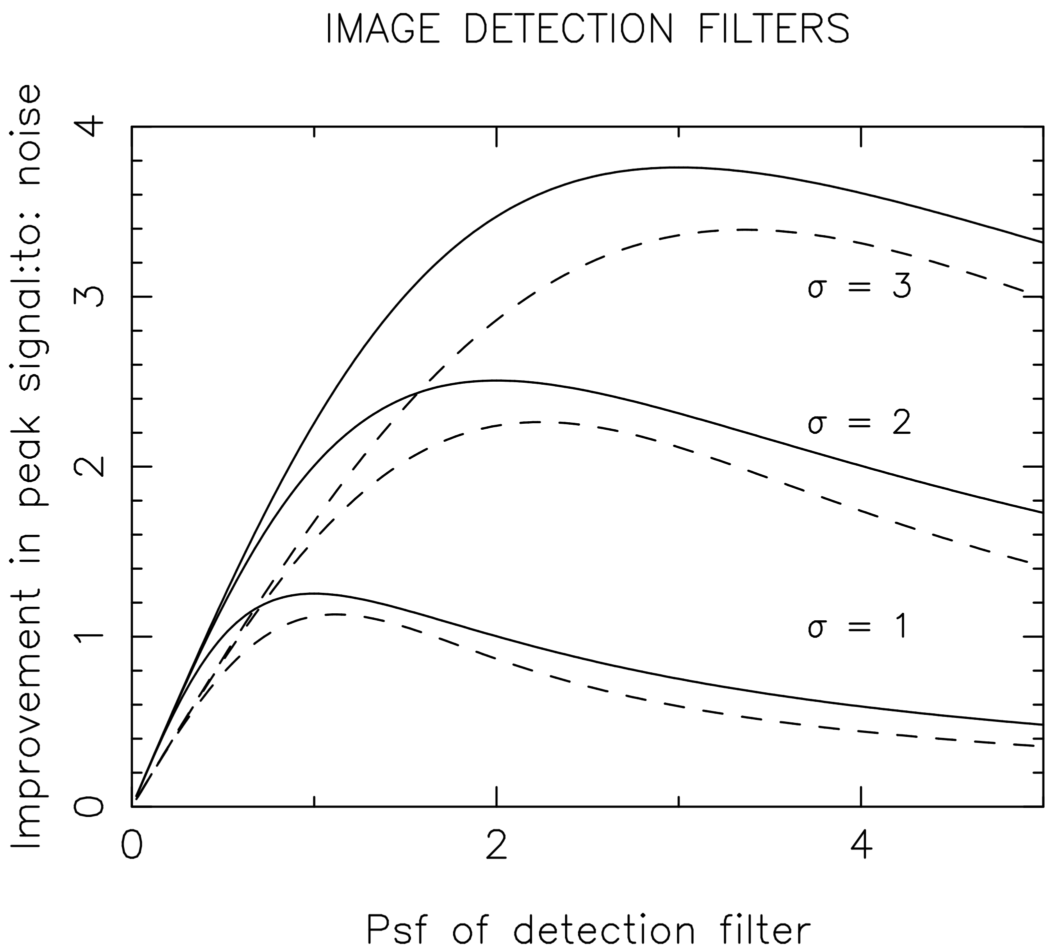
IMAGE IDENTIFICATION



MATCHED FILTERS

a matched filter maximises the resultant peak signal:to:*rms* noise.

eg. for a two-dimensional target profile $I = I_p.exp(-r^2/\sigma^2)$



using a normalised detection filter as $I = exp(-r^2/\sigma_g^2)/\pi\sigma_g^2$ changes the peak intensity, $I_p \rightarrow I_p \div (1 + \frac{\sigma_g^2}{\sigma^2})$, and changes the noise, $< \epsilon^2 >^{\frac{1}{2}} \rightarrow < \epsilon^2 >^{\frac{1}{2}} \div \sqrt{2\pi\sigma_g^2}$.

for a normalised circular top-hat filters of radius, a, the improvement becomes $\sqrt{\pi a^2} \times \sigma^2/a^2 \times [1 - exp(-a^2/\sigma^2)]$.

IMAGE PARAMETERS

Isophotal Intensity:

$$I_{iso} = \sum_i I(x_i, y_i)$$

Position:

$$x_o = \sum_i x_i.I(x_i, y_i) / \sum_i I(x_i, y_i)$$
$$y_o = \sum_i y_i.I(x_i, y_i) / \sum_i I(x_i, y_i)$$

Covariance Matrix:

$$\sigma_{xx} = \sum_i (x_i - x_o)^2 I(x_i, y_i) / \sum_i I(x_i, y_i)$$
$$\sigma_{xy} = \sum_i (x_i - x_o).(y_i - y_o).I(x_i, y_i) / \sum_i I(x_i, y_i)$$
$$\sigma_{yy} = \sum_i (y_i - y_o)^2 I(x_i, y_i) / \sum_i I(x_i, y_i)$$

Areal Profile:

Area of image at levels $\rightarrow \quad T + p_1, T + p_2, T + p_3, ...T + p_8$

Peak Height:

$$I_p = max[I(x_i, y_i)]_i$$

Kron:

$$r_1 = \int r.I(r)dr / \int I(r)dr; \; r_{-2} = \int r^{-2} I(r)dr / \int I(r)dr$$

OBJECT PARAMETER ESTIMATION

PHOTOMETRY

isophotal - the integrated flux within the boundary defined by the threshold level; ie. 0th moment

$$I_{iso} = \sum_i I(x_i, y_i)$$

For Gaussian images, $I_{tot} = I_{iso}/(1 - I_t/I_p)^{-1}$, where I_p is the peak flux and I_t the threshold relative to sky

for images close to the detection limit, $I_p \approx 2I_t$, isophotal magnitudes will be around 1 magnitude fainter than total magnitudes.

aperture - the integrated flux within some radius r

$$I_{ap}(r) = \sum_i^N I_i - N \times sky$$

depends critically on the sky estimate

the radius r is chosen as a compromise between: capturing all the light, and adding in too much sky noise $= \sqrt{N} \times \sigma_{sky}$;

and being mislead by systematic errors in the sky level $= N \times \Delta_{sky}$.

use the curve-of-growth, $I_{ap}(r)$ -v- r,

profile fitting - only possible for stars, requires point source psf

for a single image it reduces to a weighted sum over pixels vital when the image is a blend of several components

POSITION

2D isophotal centre of gravity

$$x_o = \sum_i x_i.I(x_i, y_i) / \sum_i I(x_i, y_i)$$

$$y_o = \sum_i y_i.I(x_i, y_i) / \sum_i I(x_i, y_i)$$

1D marginal profile method

form $\rho(x_i) = \sum_{j=-a}^{j=+a} I_{i,j}$ and equivalently $\rho(y_i)$

then find the centre of the one-dimensional distributions

simple and fast, usually not so good as using the full 2-d information,

PSF fitting and general weighted 2-d centre of gravity estimates

$$\bar{x} = \frac{\sum_i w_i \times x_i \times I_i}{\sum_i w_i \times I_i}$$

for an image profile $\phi(x, y)$, the optimum weight function is

$$w_i = \left[\frac{1}{x - \bar{x}} \times \frac{\partial \phi}{\partial x}\right]_i \times \frac{1}{\sigma_i^2}$$

for a Gaussian this reduces to $w_i \propto \phi(x_i, y_i)/\sigma_i^2$

requires an iterative solution

SHAPE

the Covariance Matrix is the triad of intensity-weighted 2nd moments and is used to estimate the eccentricity/ellipticity, position angle and intensity-weighted size of an image

$$\sigma_{xx} = \sum_i (x_i - x_o)^2.I(x_i, y_i) / \sum_i I(x_i, y_i)$$

$$\sigma_{xy} = \sum_i (x_i - x_o).(y_i - y_o).I(x_i, y_i) / \sum_i I(x_i, y_i)$$

$$\sigma_{yy} = \sum_i (y_i - y_o)^2.I(x_i, y_i) / \sum_i I(x_i, y_i)$$

for elliptical Gaussian function these are related to the size, eccentricity, and position angle as follows

the scale size, $\sqrt{\sigma_{rr}} = \sqrt{\sigma_{xx} + \sigma_{yy}}$

the eccentricity, $ecc = \sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4.\sigma_{xy}^2} \ / \ \sigma_{rr}$

the position angle, θ is defined by, $tan(2\theta) = 2.\sigma_{xy}/(\sigma_{yy} - \sigma_{xx})$.

Higher order moments have been used as shape descriptors but are generally much more prone to corruption by outlying noisy data pixels.