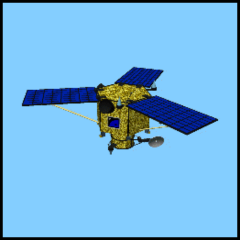
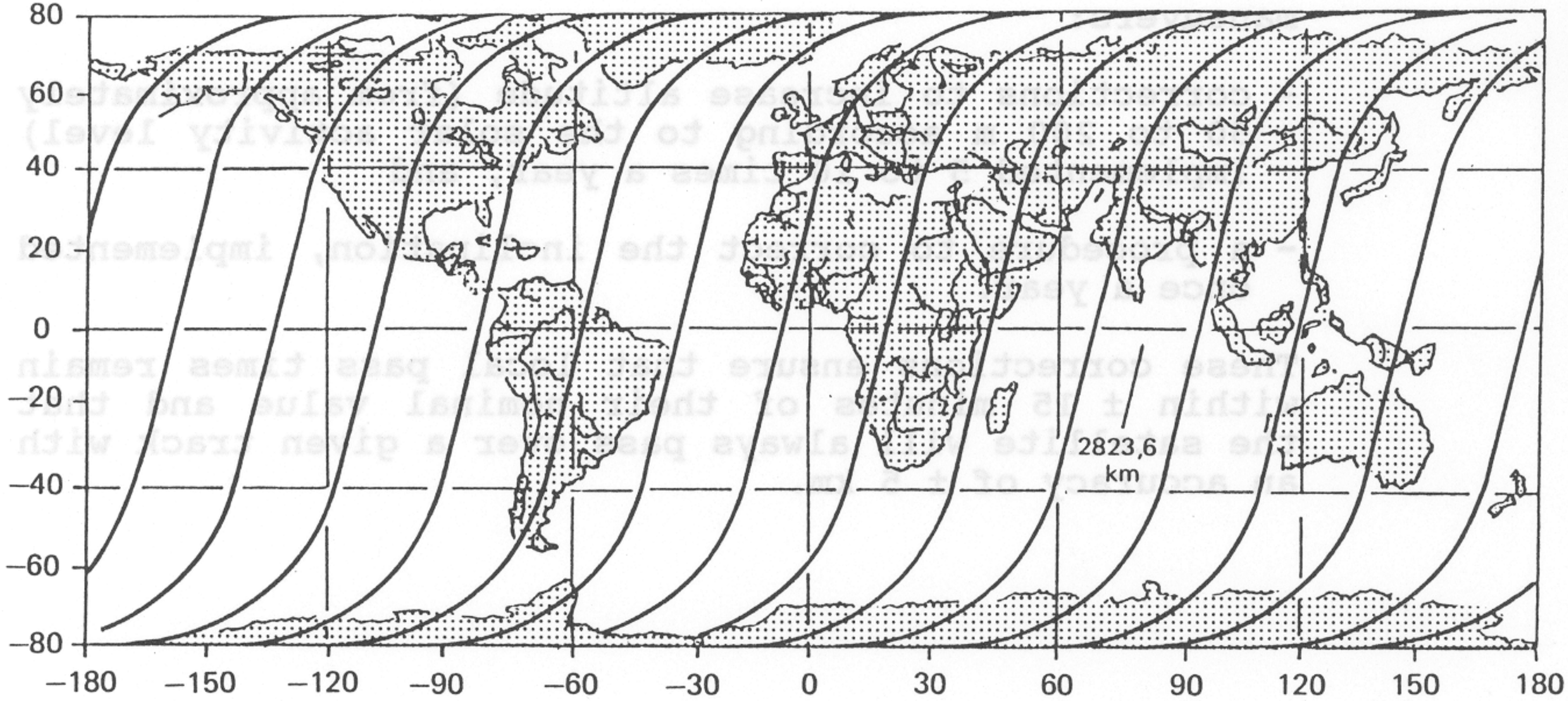


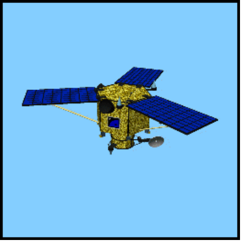
Classical Remote Sensing Requirements

- Fundamental requirement: allow comparison of images acquired over the same area on different dates (surveillance, monitoring, change detection)
- Also: allow comparison of images among different scenes
- These overall mission requirements impose secondary requirements on parameters of the system
    - Constant scale everywhere implies a *circular orbit* (SPOT: alt. = 822 km)
    - Image *any* region of the earth, this implies a *polar or near polar orbit*, (SPOT: inclination = 98.7 degrees)
    - Revisit any location and acquire essentially the same image, this requires design of *imaging cycle or repeat cycle*. (SPOT: 26 days per cycle)
    - Acquire all images with same sun angle, this imples a *sun synchronous orbit*

SPOT: Ground Track for One Day



From Spot User’s Handbook

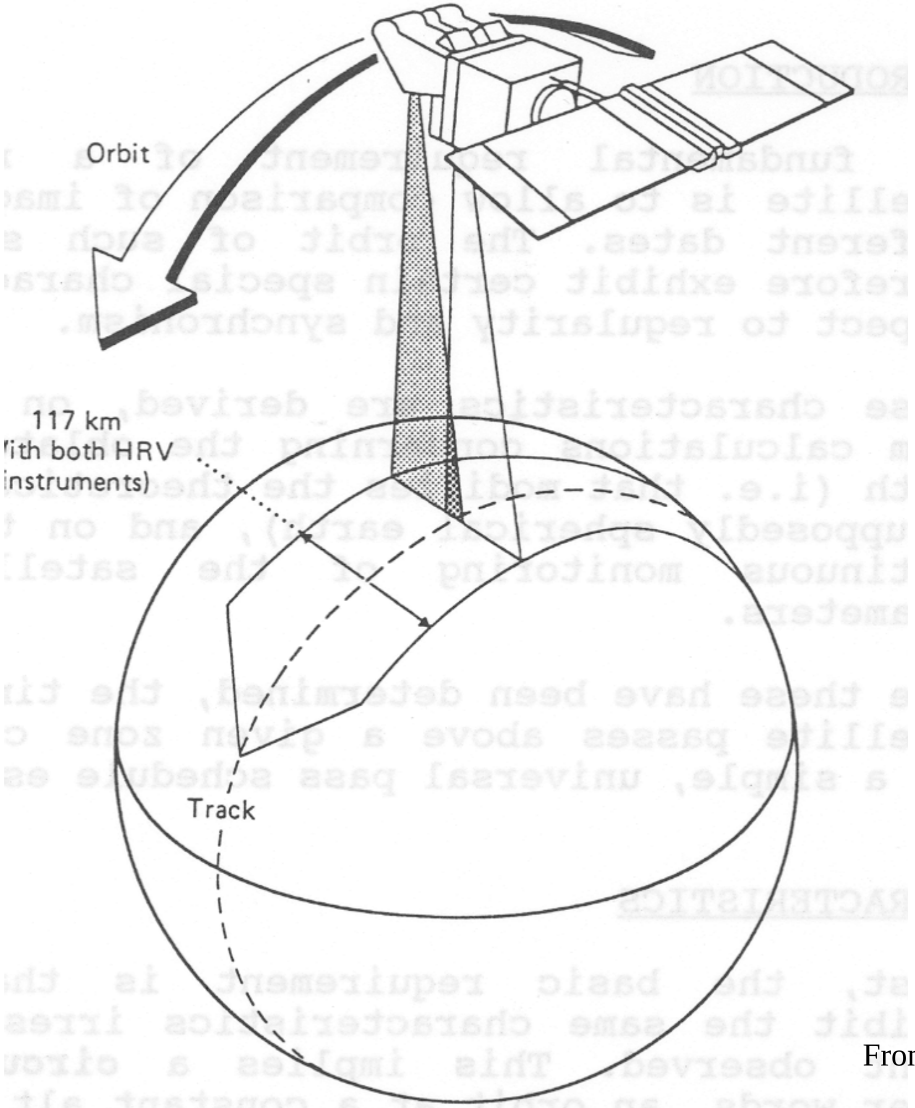


SPOT Swath Width

Each instrument: 6000 pixels @ 10m (panchromatic band) =>

60,000m or 60km

Note: MS bands are 3000 pixels @ 20m, 4x detector area since we have reduced incident energy due to bandpass filtering

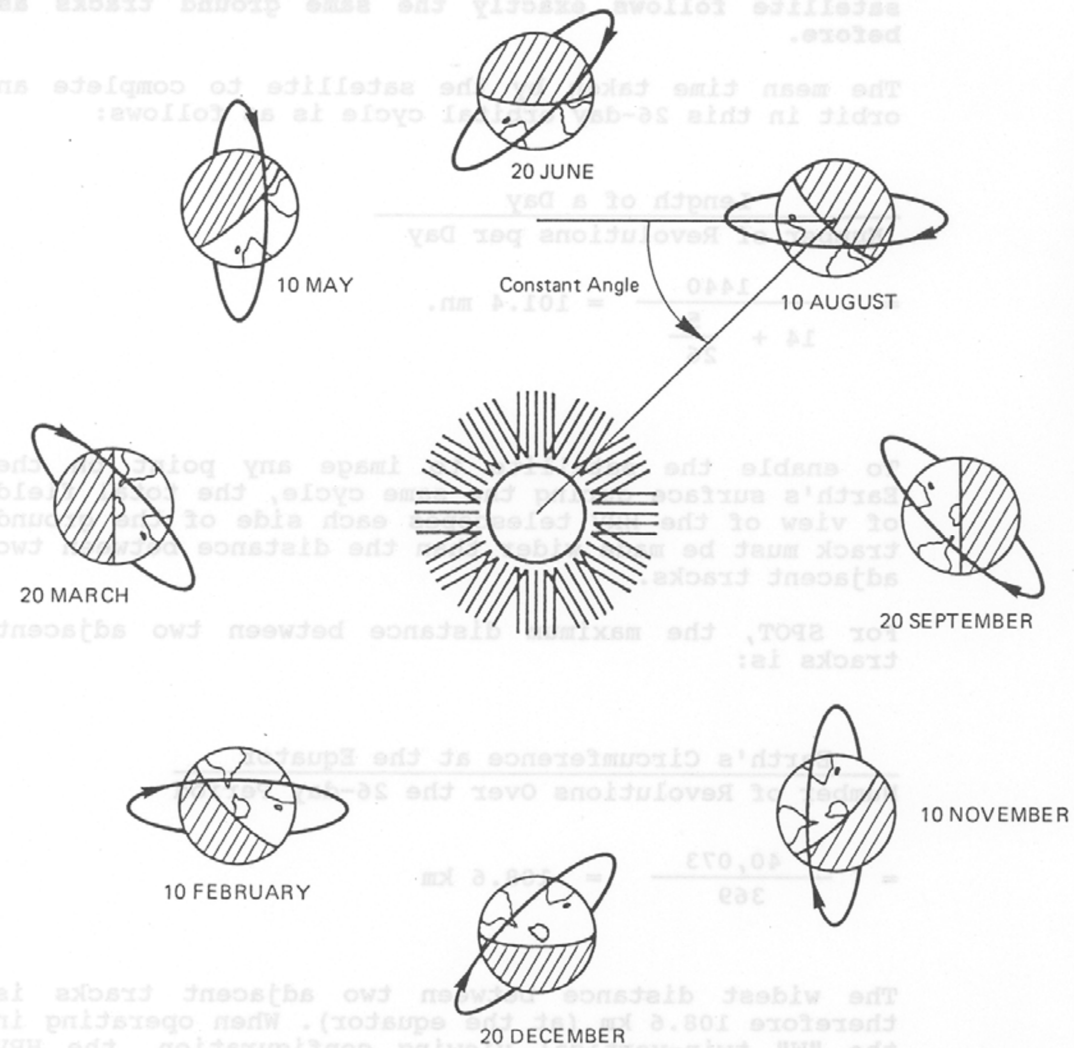


Near polar, circular orbit, altitude = 822 km

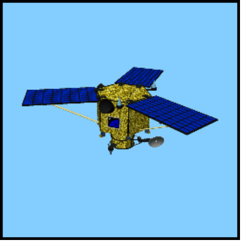
From Spot User’s Handbook

Sun Synchronous Orbit: Constant Sun Angle

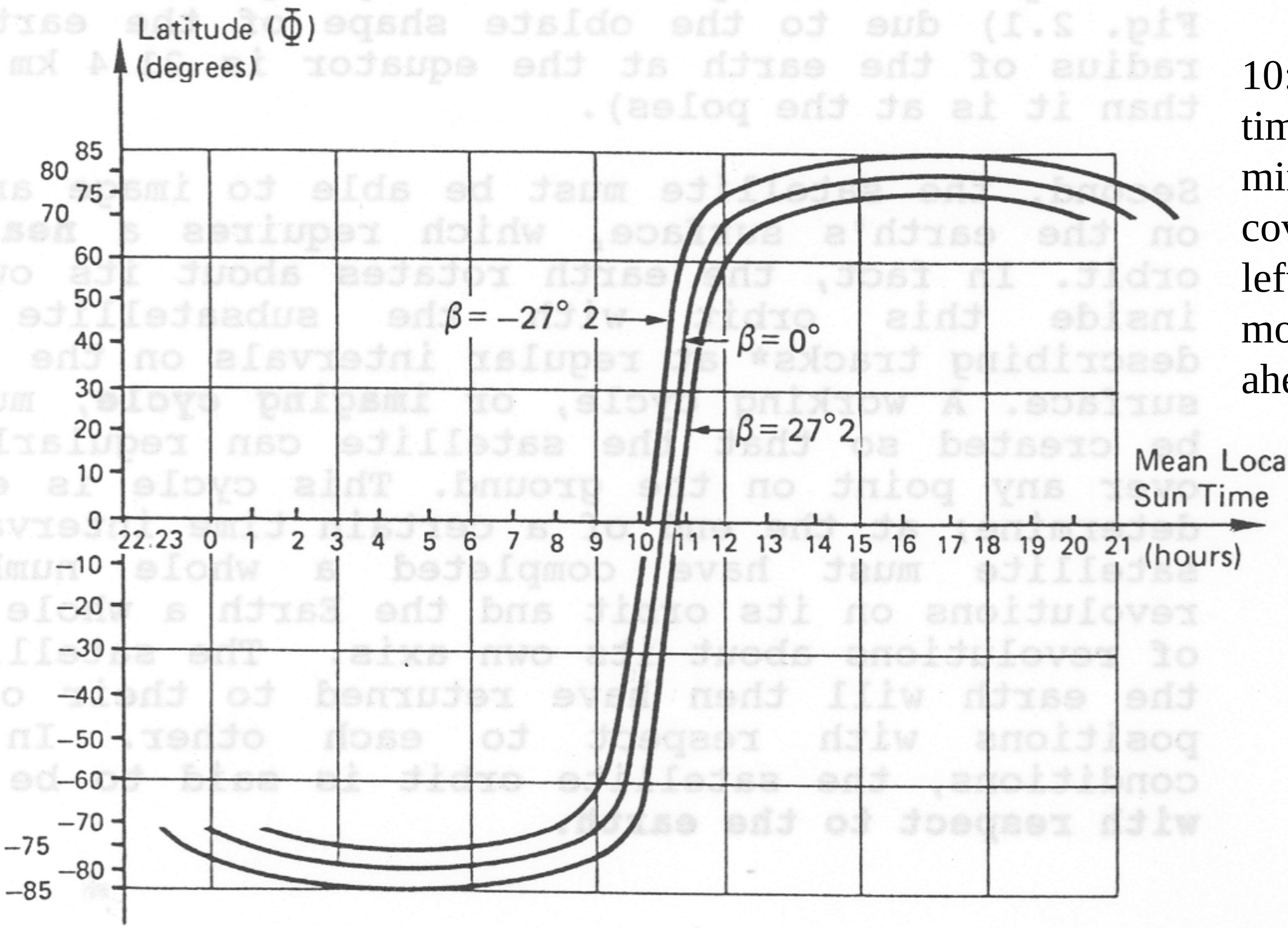
Orbit must precess once per year (with respect to the stars). This rate can be controlled by altitude and inclination.



From Spot User's Handbook



Time of Passage, Function of Latitude



10:30 am local time chosen to minimize cloud cover. Looking left or right moves the time ahead or behind

From Spot User's Handbook

SPOT Pushbroom Geometry

Focal length: 1.082m

Line rate: 1.504 ms

FOV: 4.18 degrees

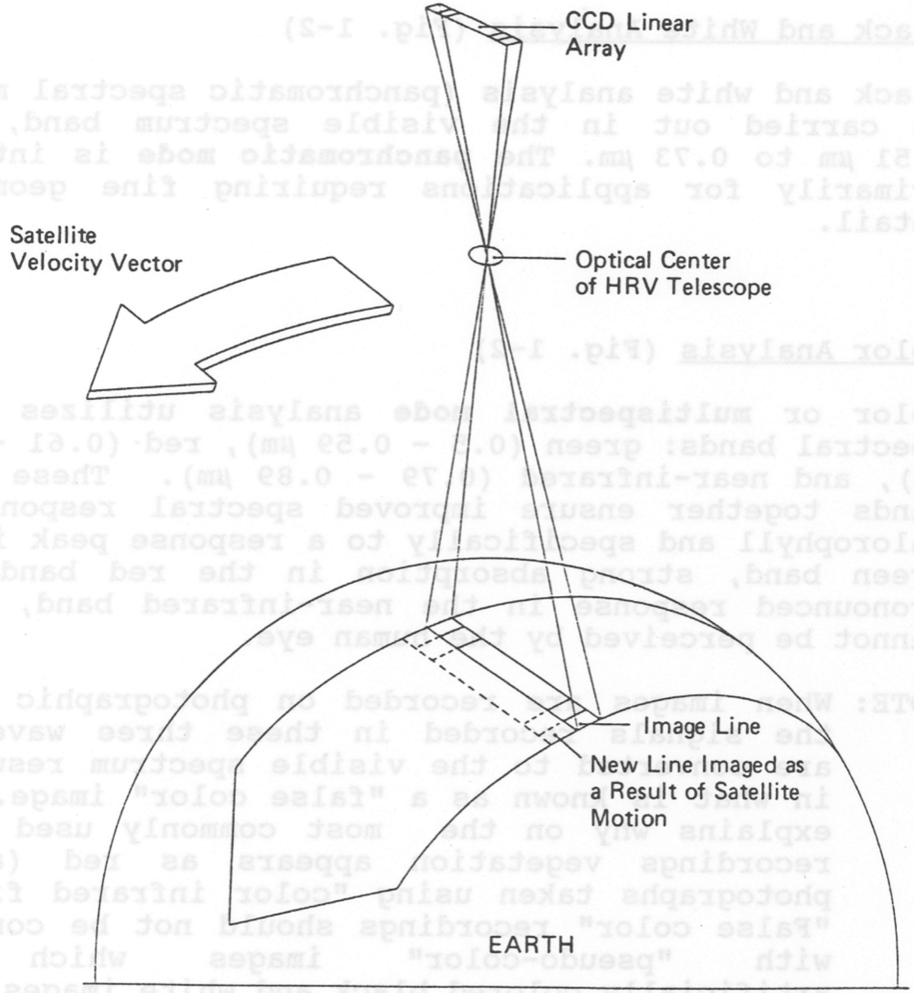
Period: 101.4 min

Ground Speed: 6.56 km/s

IFOV: 12.2 micro radians, or 13.1 micrometers at focal plane

Aperture: 0.33 m

F/#: 3.3



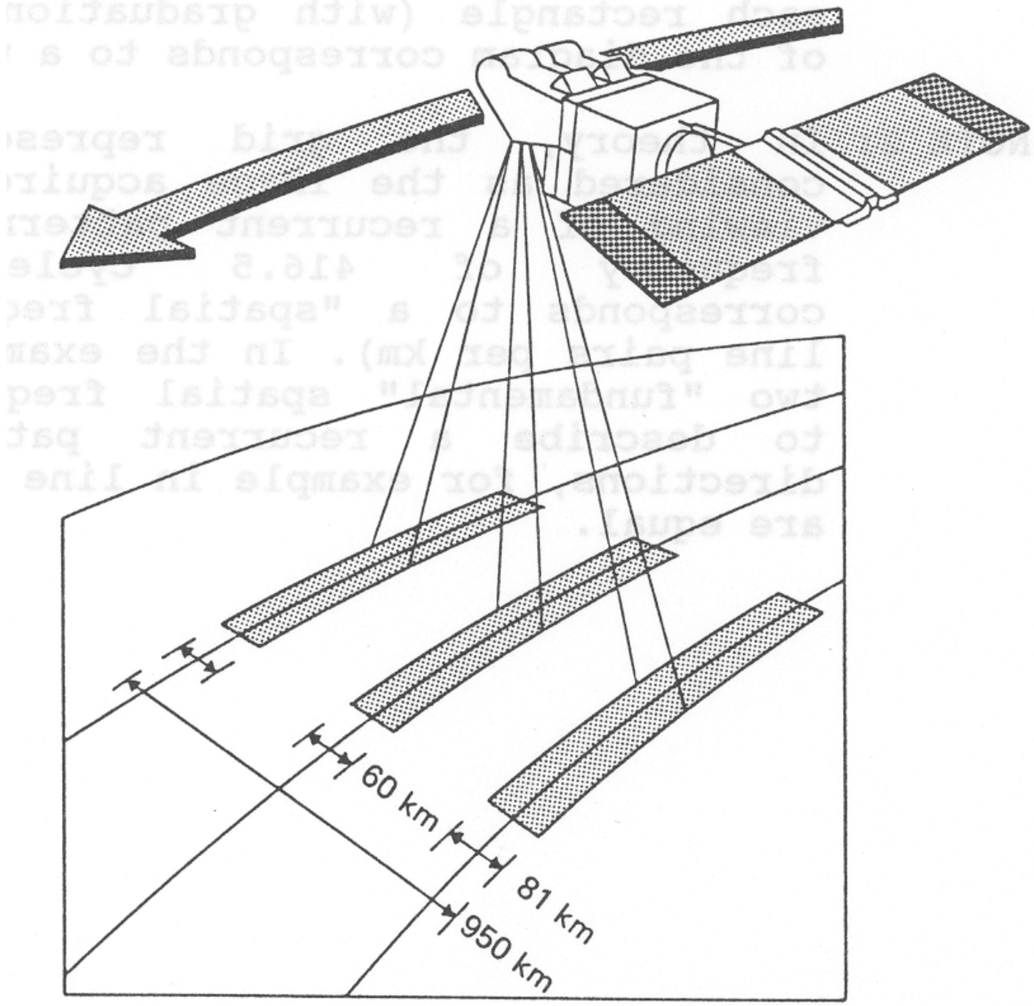
From Spot User's Handbook

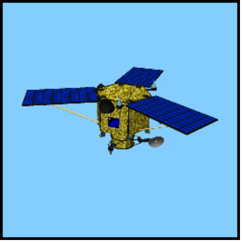
SPOT Field of Regard, FOR

Can look left or right by 27 degrees

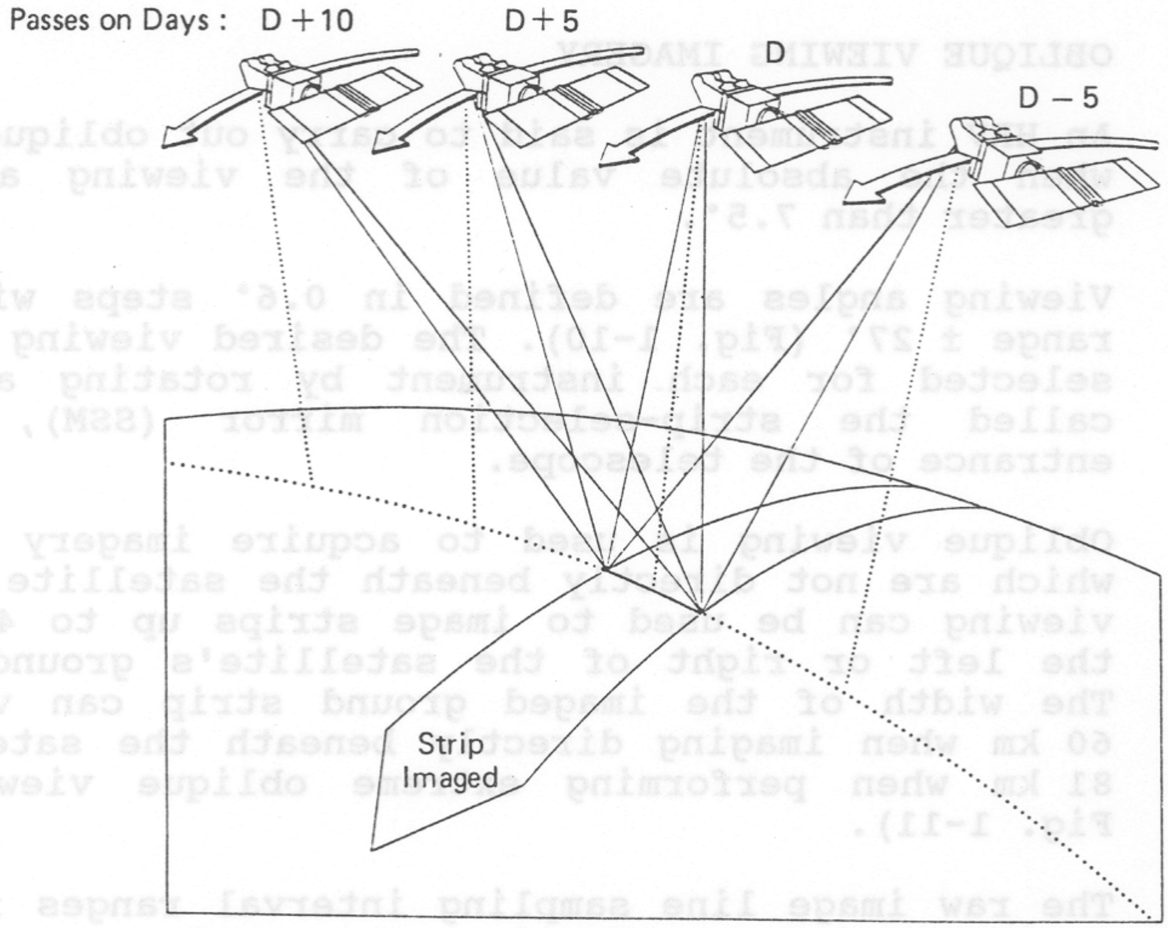
FOR = 54 degrees

“Strip Selection Mirror” stationary during image acquisition



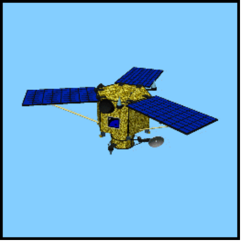


Cross-track Stereo Repeat Coverage



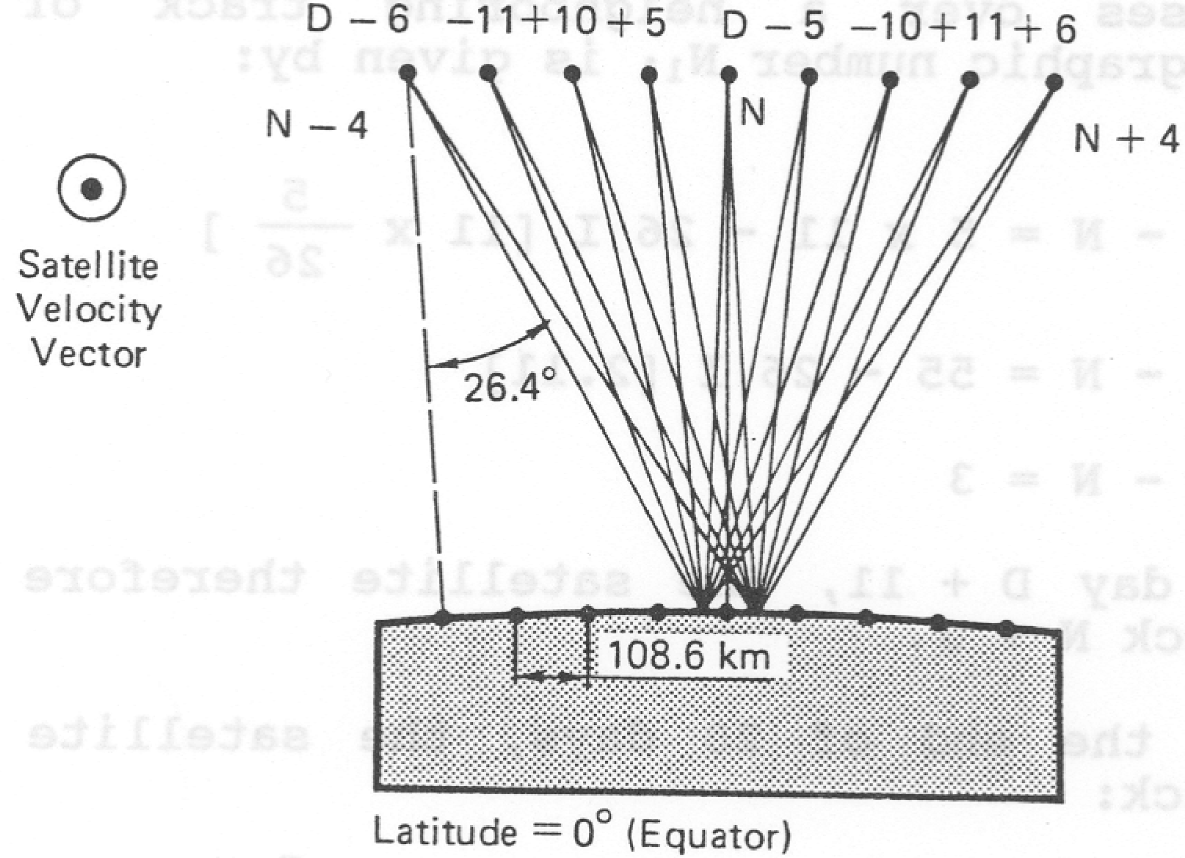
Many days can separate acquisitions of the same scene – permitting weather or seasonal effects to diminishing corresondence and stereo capabilites

From Spot User's Handbook

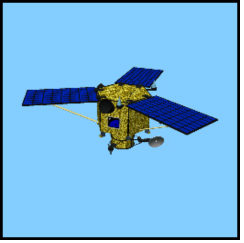


Max Nine Views of a Scene

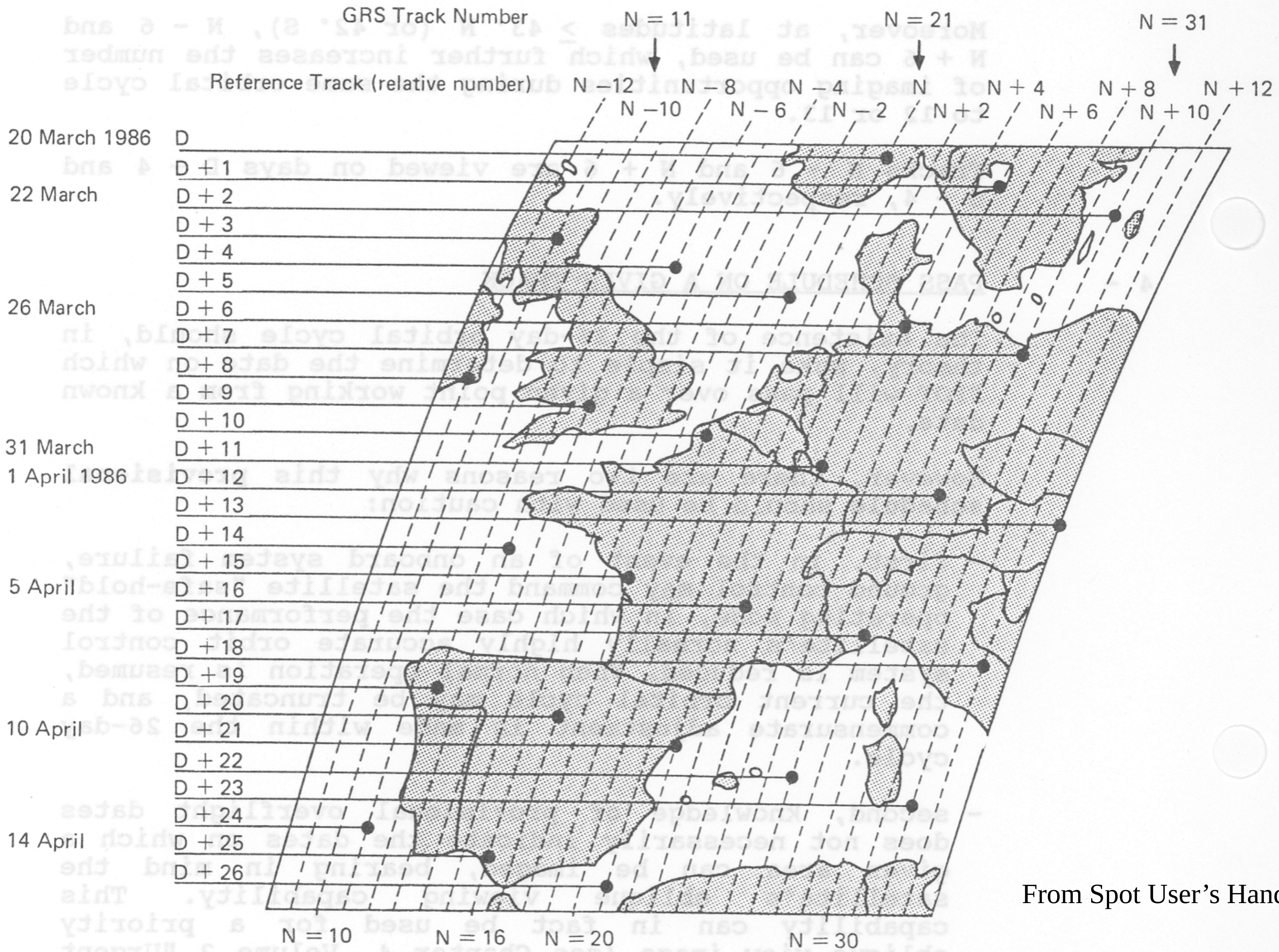
These nine views take place over 22 days



From Spot User's Handbook



SPOT Pass Schedule

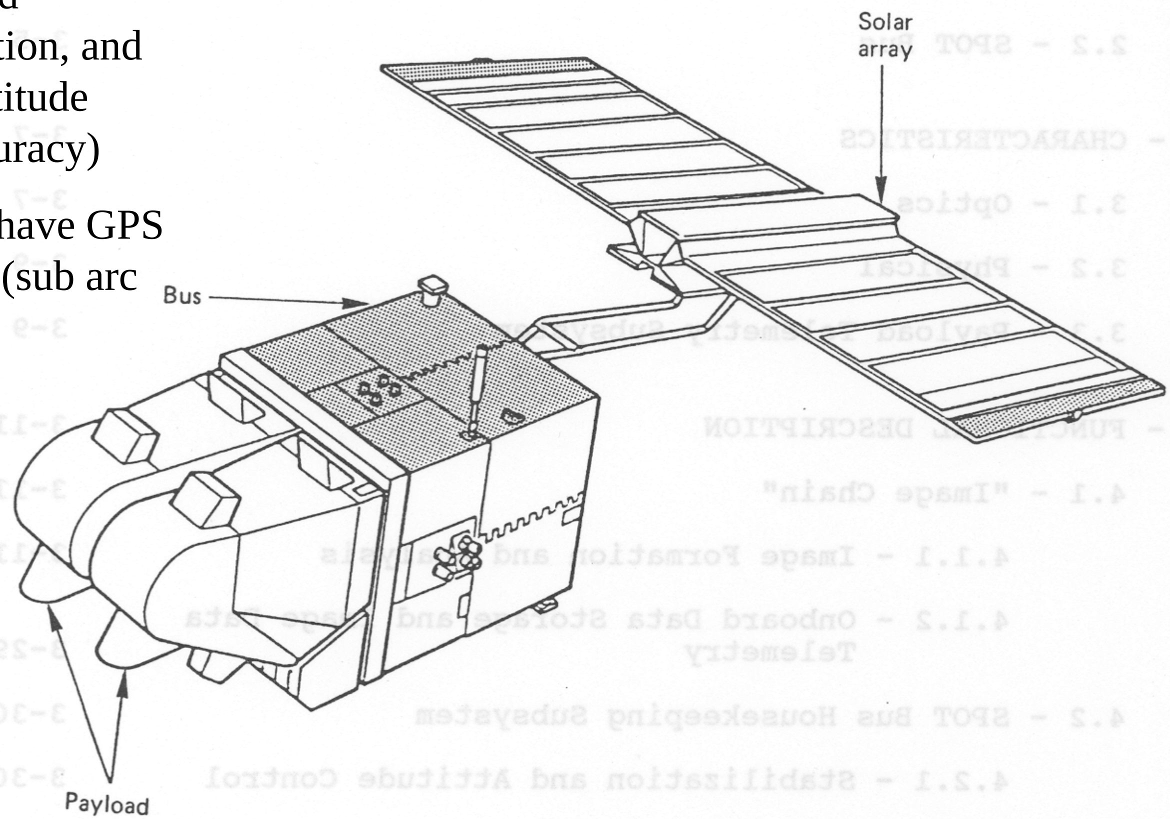


From Spot User's Handbook

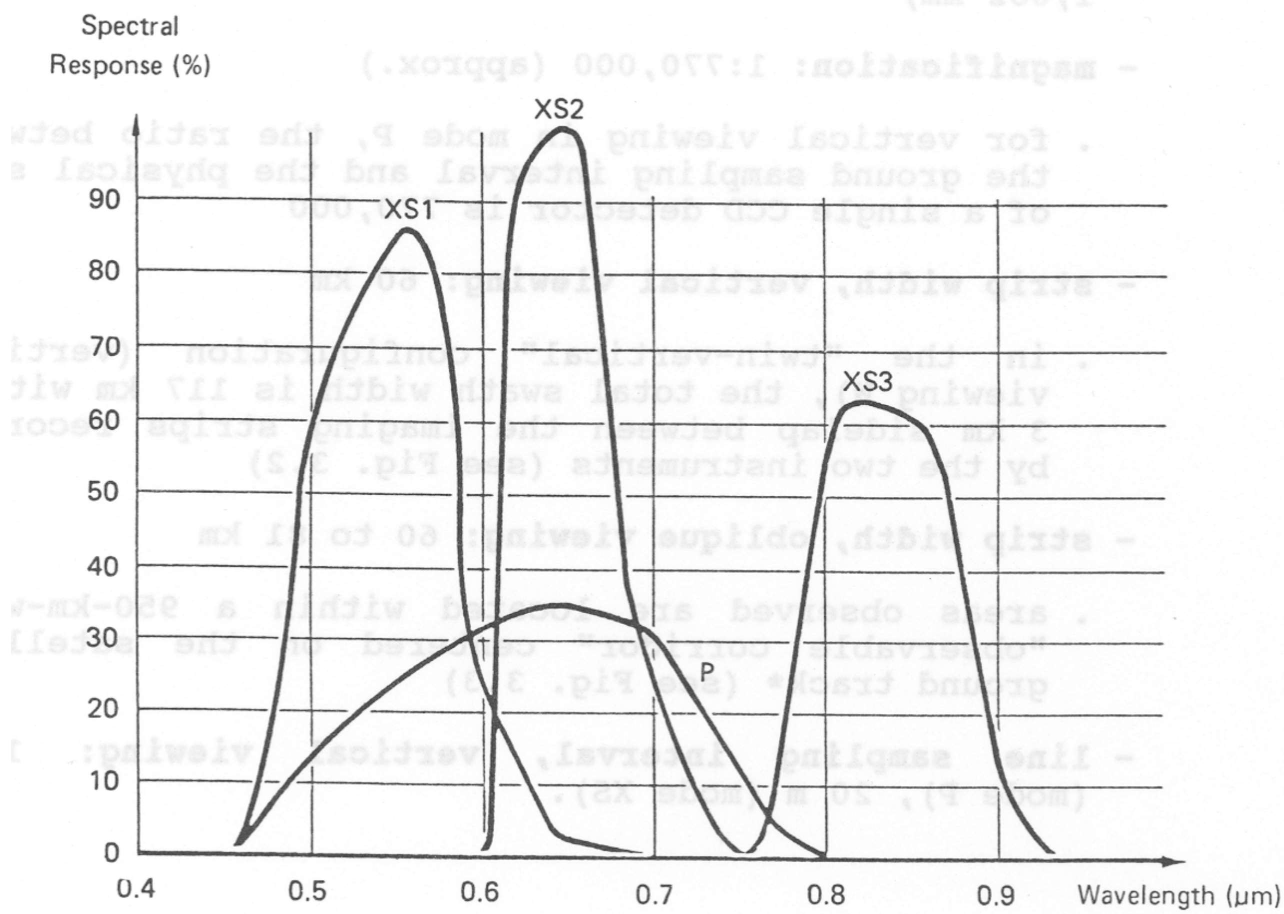
Spot Spacecraft (1-4)

Reliant on ground tracking for position, and sun sensor for attitude (0.15 degree accuracy)

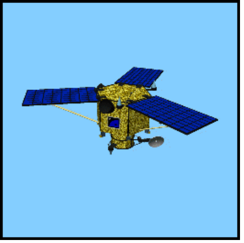
Newer satellites have GPS and star trackers (sub arc second attitude)



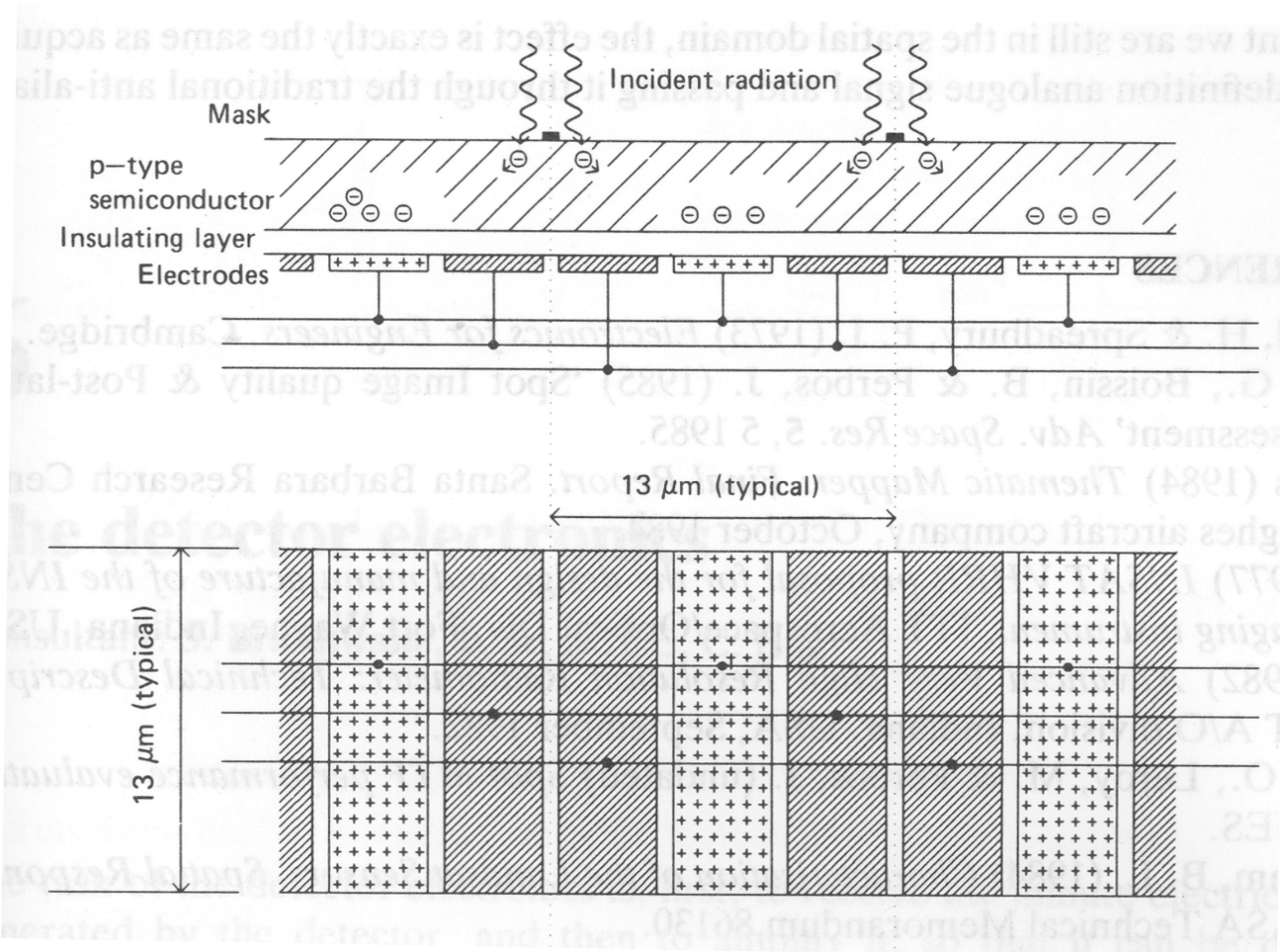
Spot Spectral Bands



From Spot User's Handbook



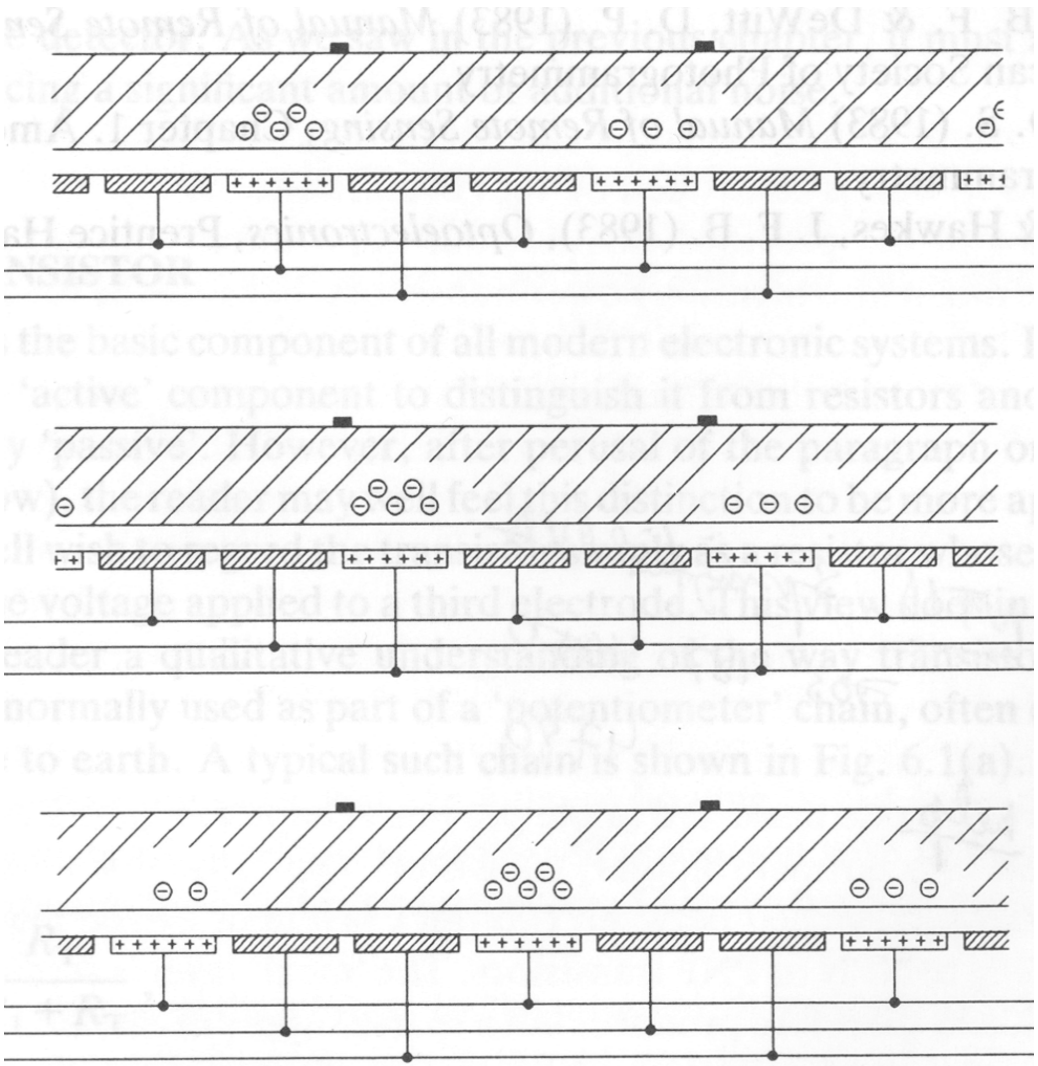
CCD Operation



Photoelectric effect causes incident photon to free an electron. These electrons gather at the positively charged electrode. After a fixed integration period, the voltage level is proportional to the intensity of the incident radiation.

From Pease, Satellite Imaging Instruments

CCD Data Readout



Data within a line is read out by shifting positive charge successively to the right by one electrode at a time. This carries the accumulated charge along with it. At the far right, at each shift, the voltage level is either measured and put onto an analog video signal, or it is digitized into a digital video signal.

From Pease, Satellite Imaging Instruments

CCD Operation - 1

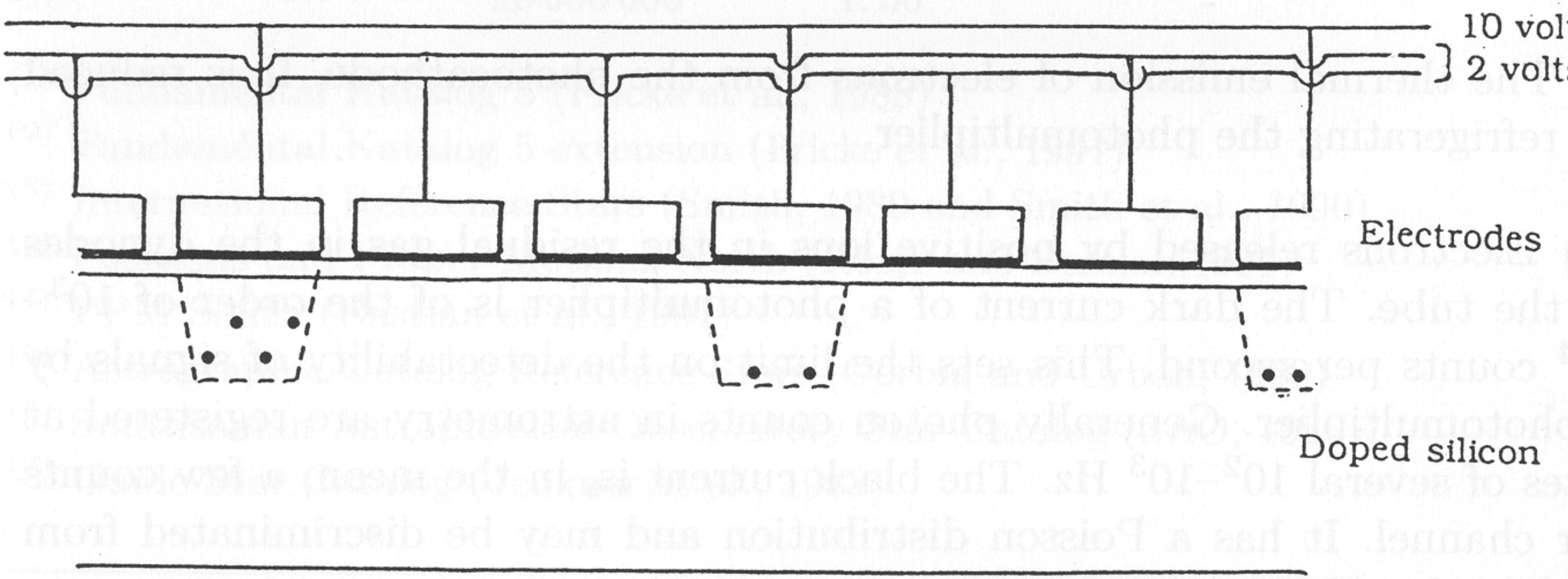
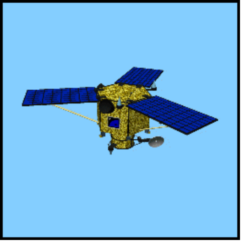


Fig. 5.5. Capture of electrons by CCD elements

From Kovalevsky, Modern Astrometry



CCD Operation - 2

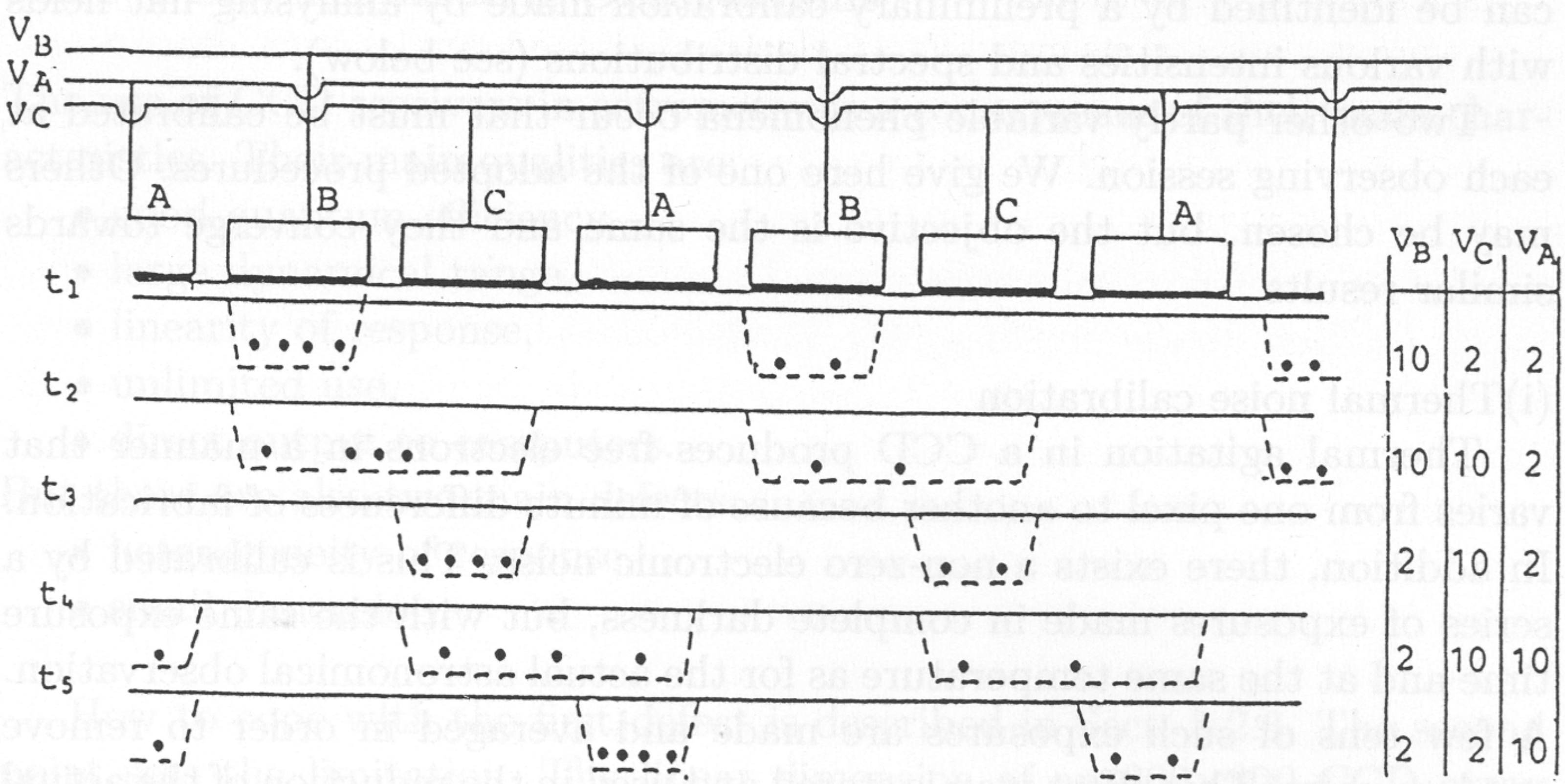
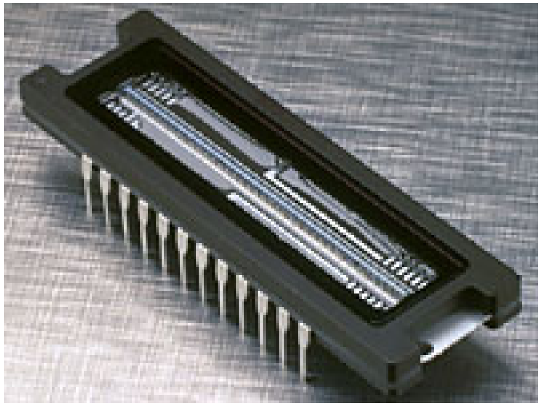


Fig. 5.6. Charge transfer in a three-phase CCD

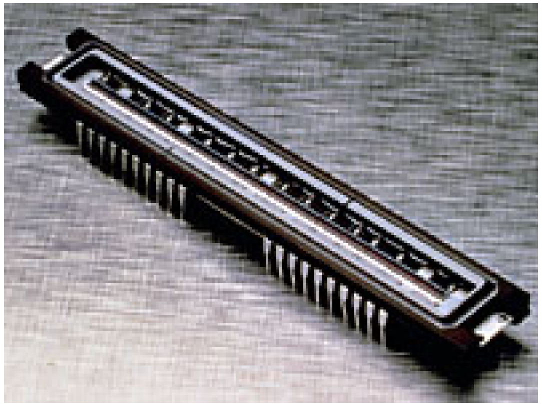
From Kovalevsky, Modern Astrometry

Some Commercial Linear CCD Arrays

Dalsa 4096 x 1



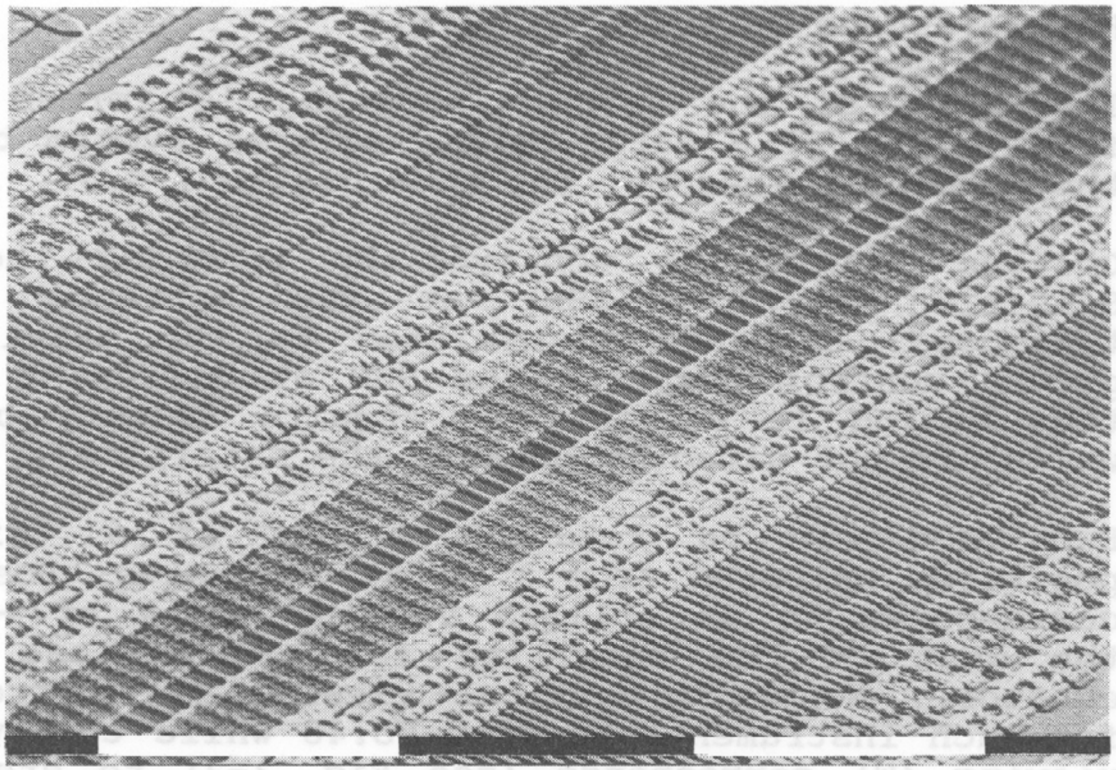
Kodak 5000 x 3



Kodak 10000 x 3

Kodak 14000 x 3

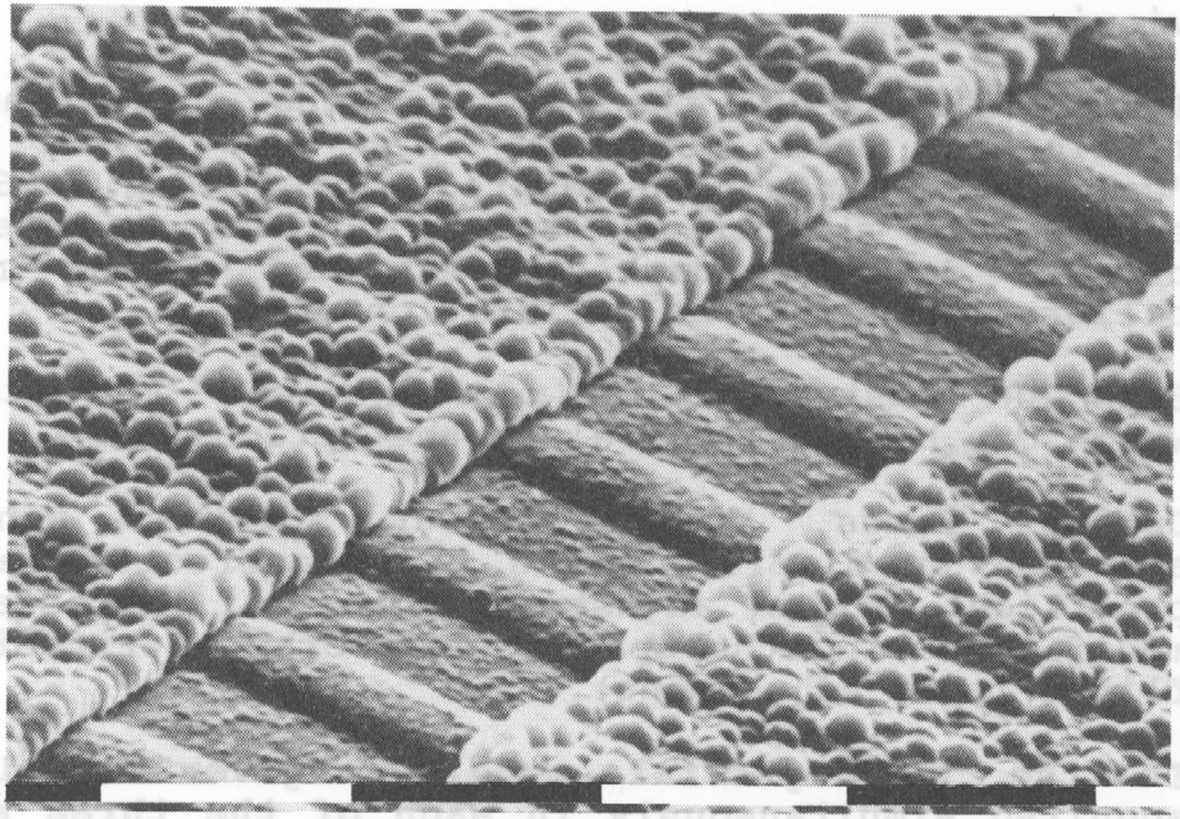
CCD Linear Array



100 μm

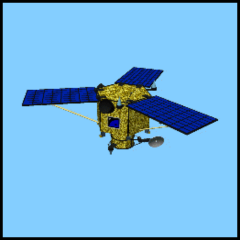
a: Portion of a Linear Array (58 photosensitive elements, or individual CCD detectors) with rows of readout registers on either side (one for even numbered detectors, the other for odd numbered detectors). (Photo courtesy of Sodern)

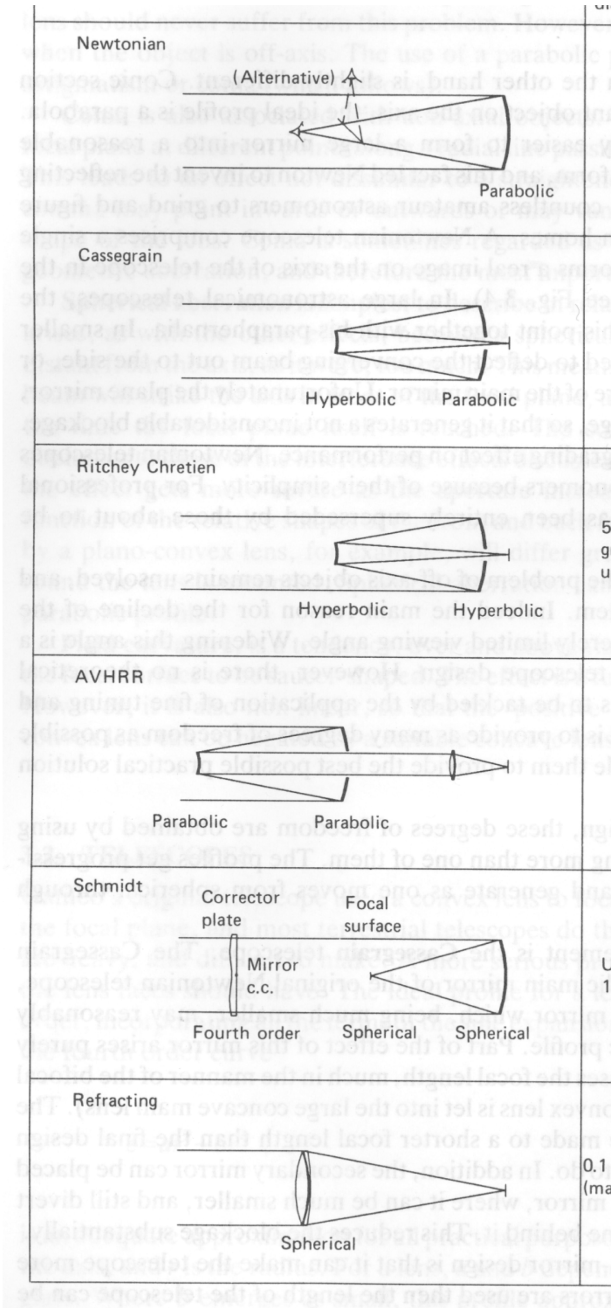
Close up of CCD Linear Array



10 μm

b: Portion of a CCD Linear Array Comprising Seven Detectors
Photo courtesy of Sodern.

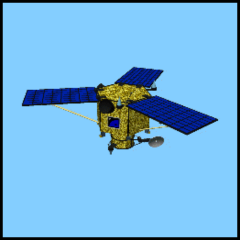




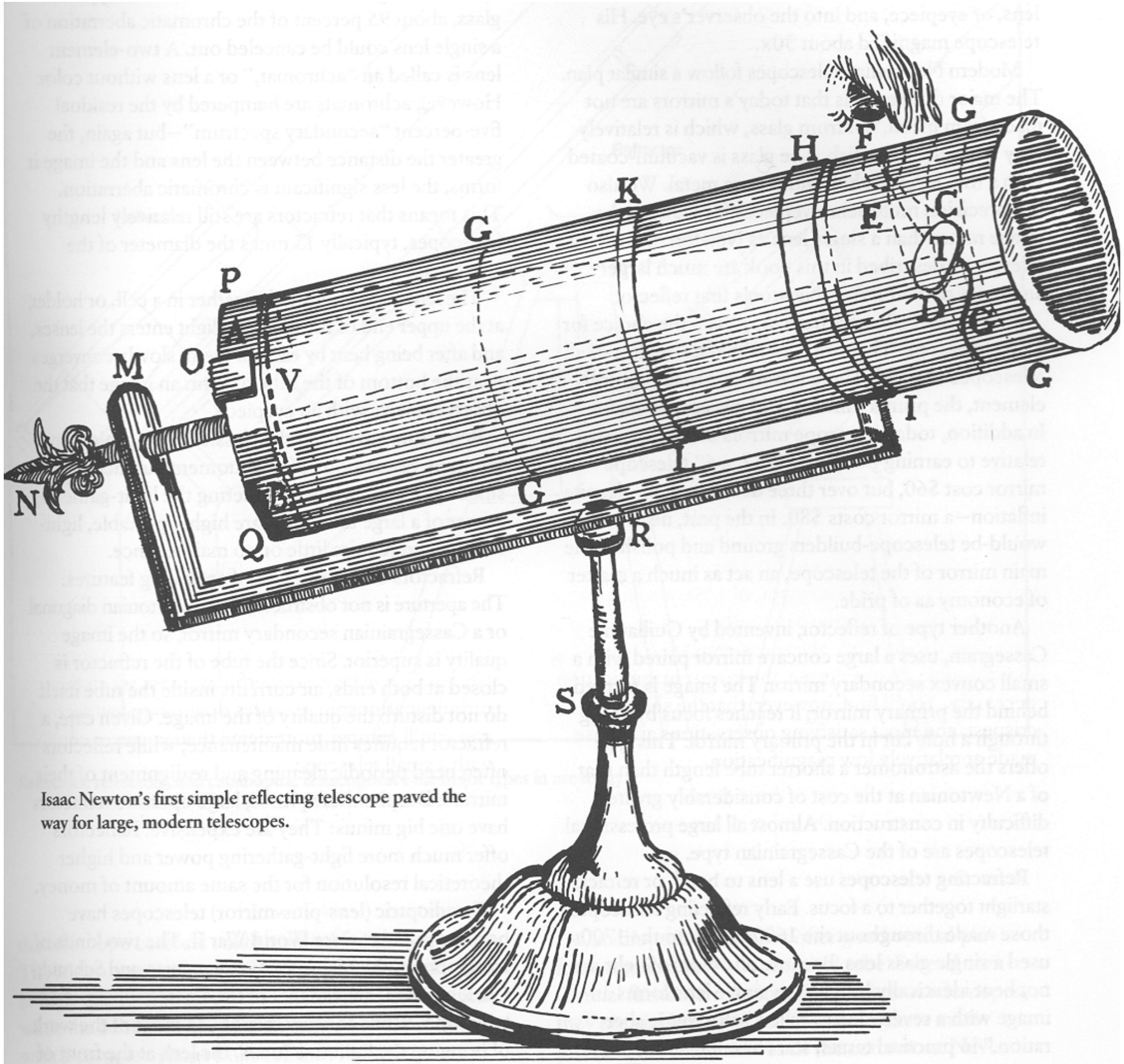
Common Telescope Types

Multi / hyperspectral imagers use a lot of *reflective* optical elements (mirrors) since they do not introduce any *chromatic aberration* (where different colors are brought to focus in different planes). Landsat uses Ritchey Chretian, SPOT uses a variant of the Schmidt telescope because of its wider field of view. Common backyard type is the Newtonian reflector

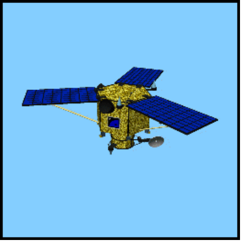
From Pease, Satellite Imaging Instruments



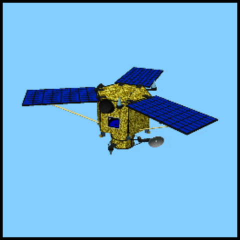
Newton’s Reflector



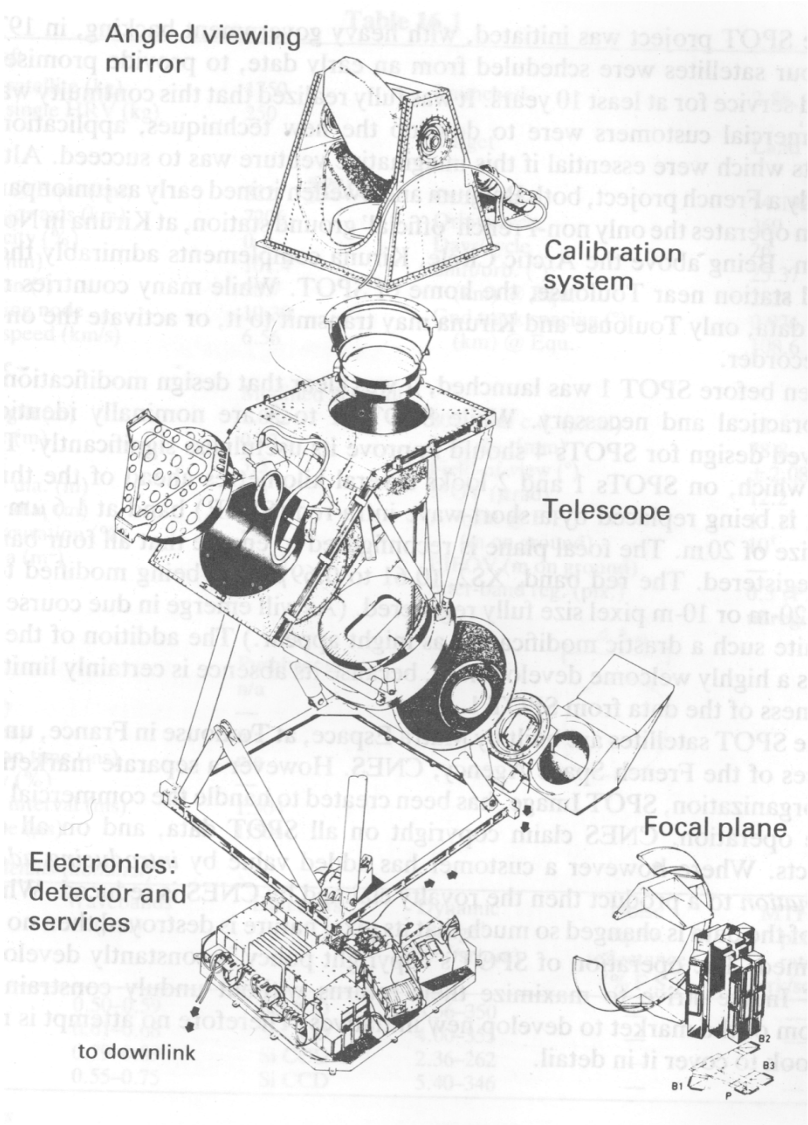
Isaac Newton’s first simple reflecting telescope paved the way for large, modern telescopes.



Newton's original reflector, 1668, at Royal Society, London

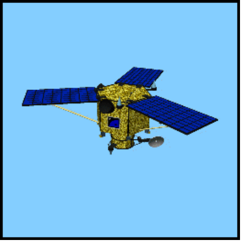


Cutaway Drawing of Spot Sensor

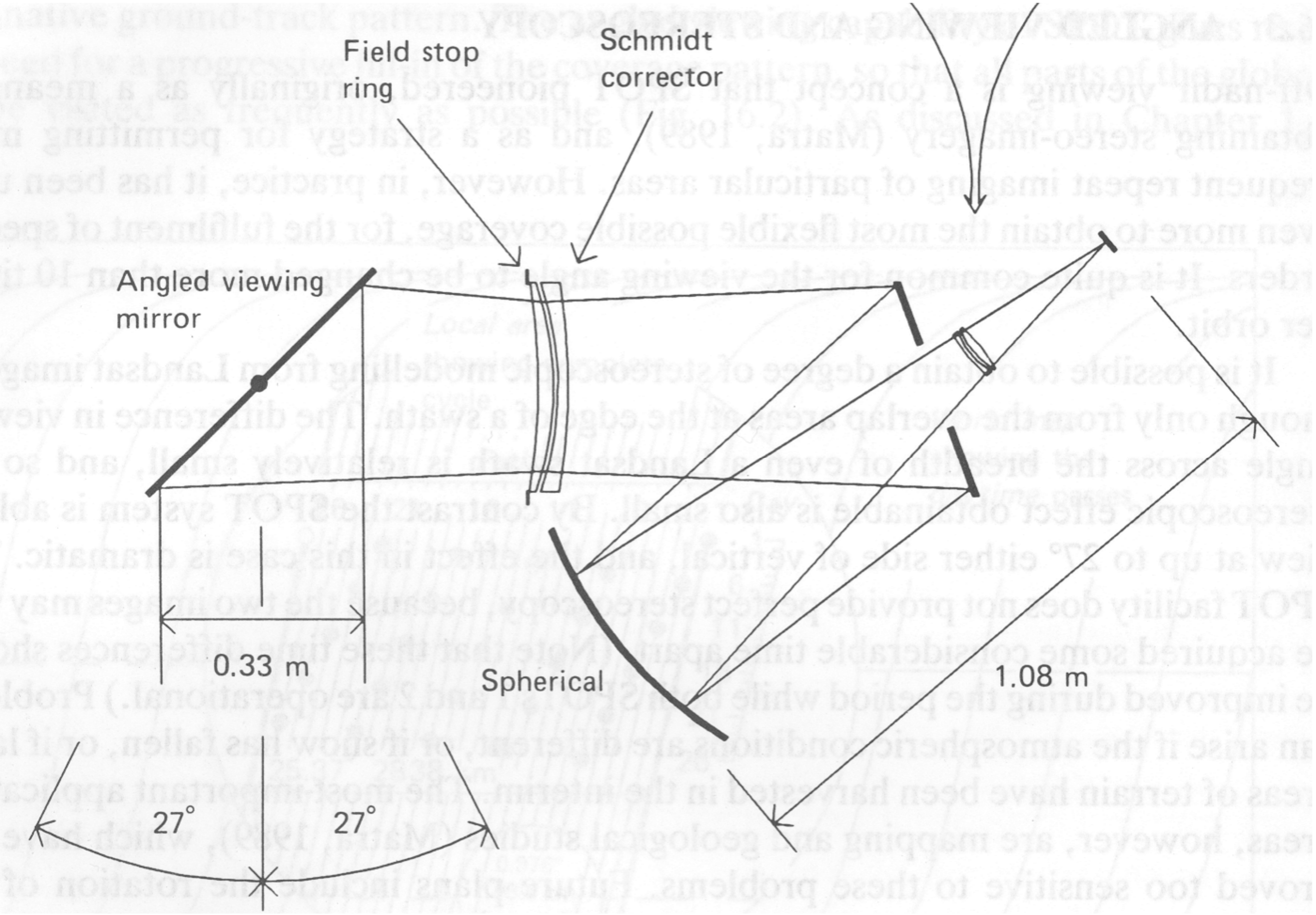


Dimensional stability is very important to maintain good focus. The structural tubes are made from carbon fiber material with a small negative thermal expansion coefficient. The titanium fittings have a positive thermal expansion coefficient that *just cancels* the tubes. (That is good engineering!)

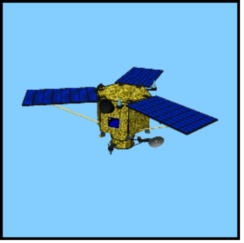
From Pease, Satellite Imaging Instruments



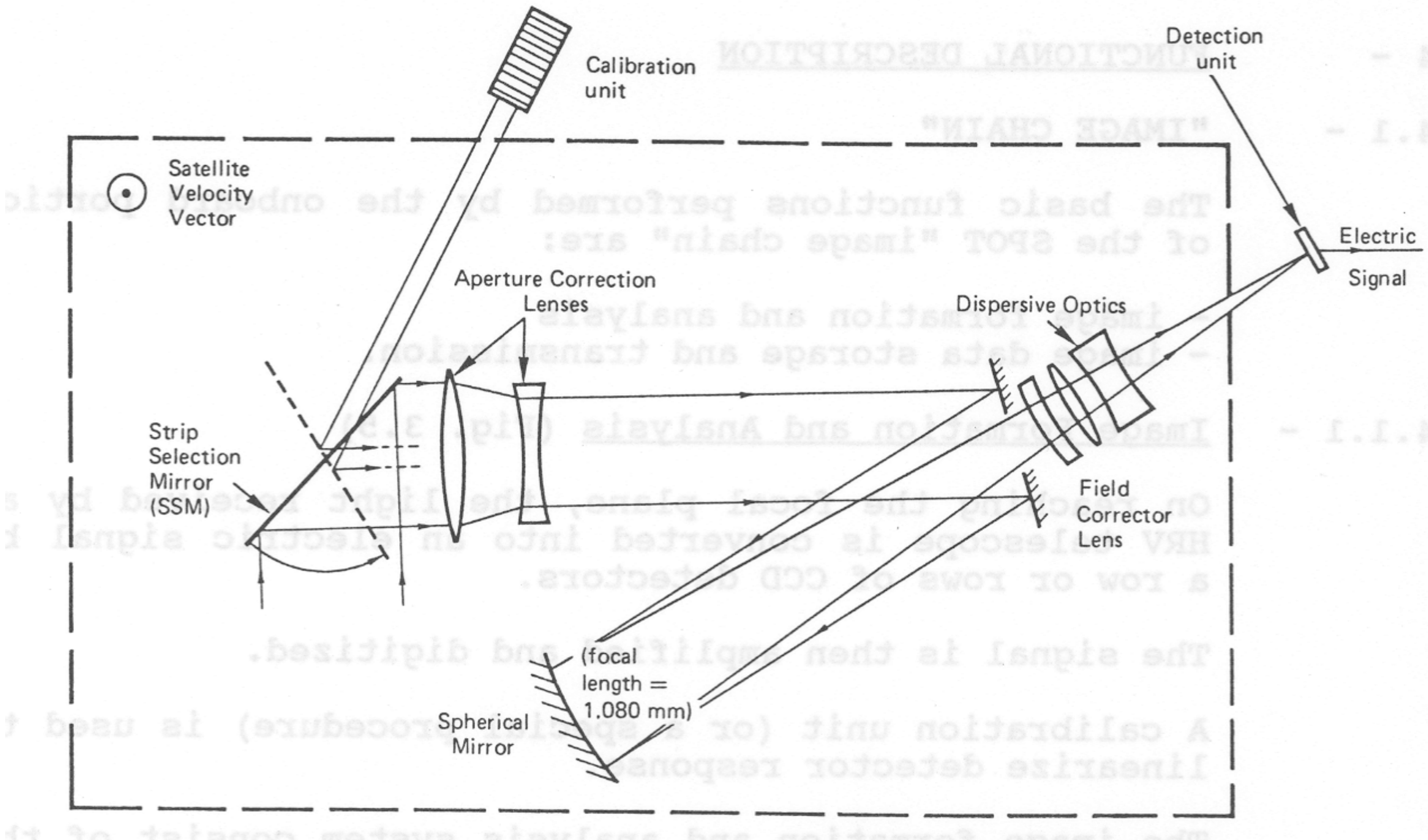
Schematic of Spot Optics



From Pease, Satellite Imaging Instruments

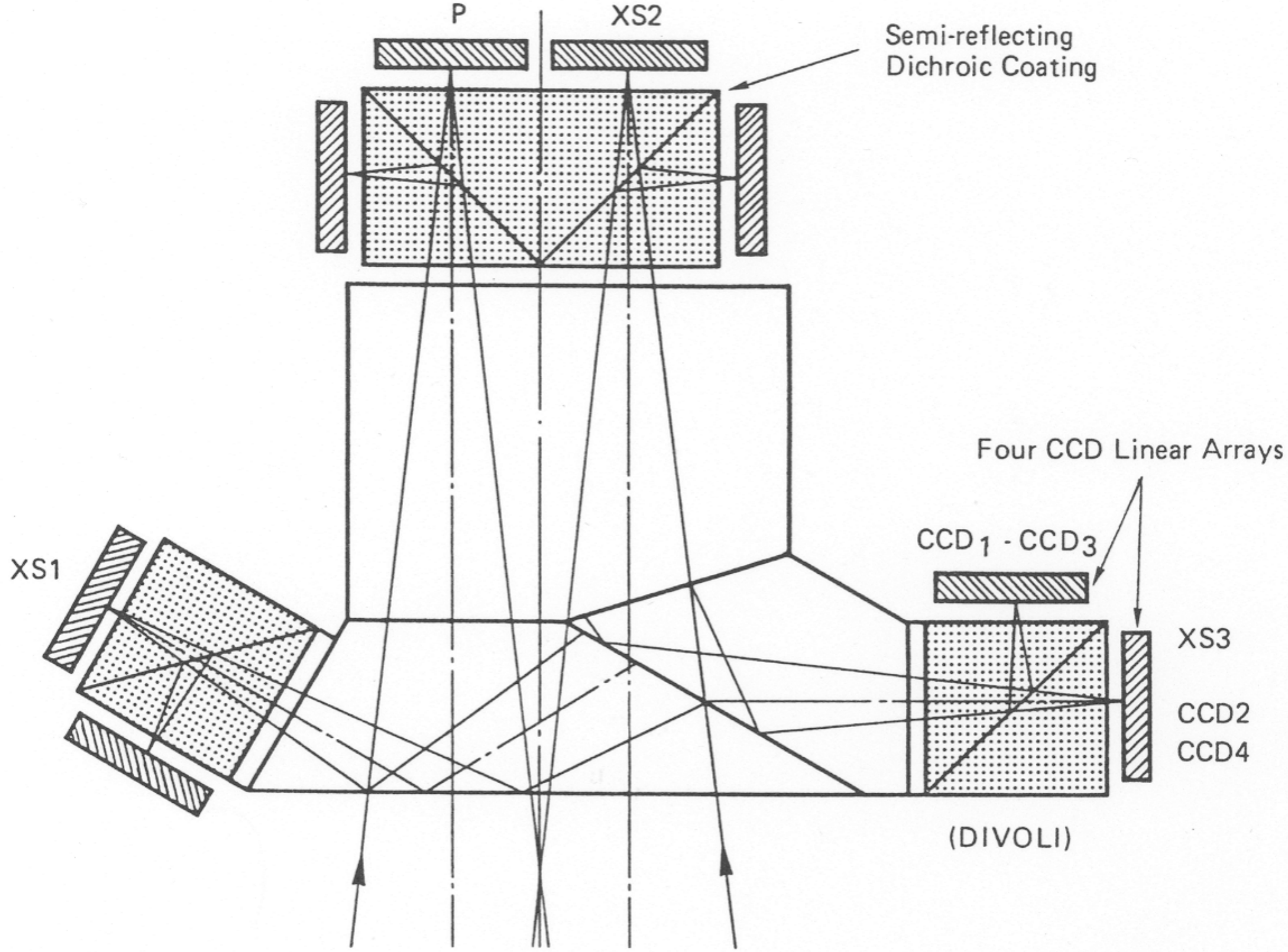


Spot Optics

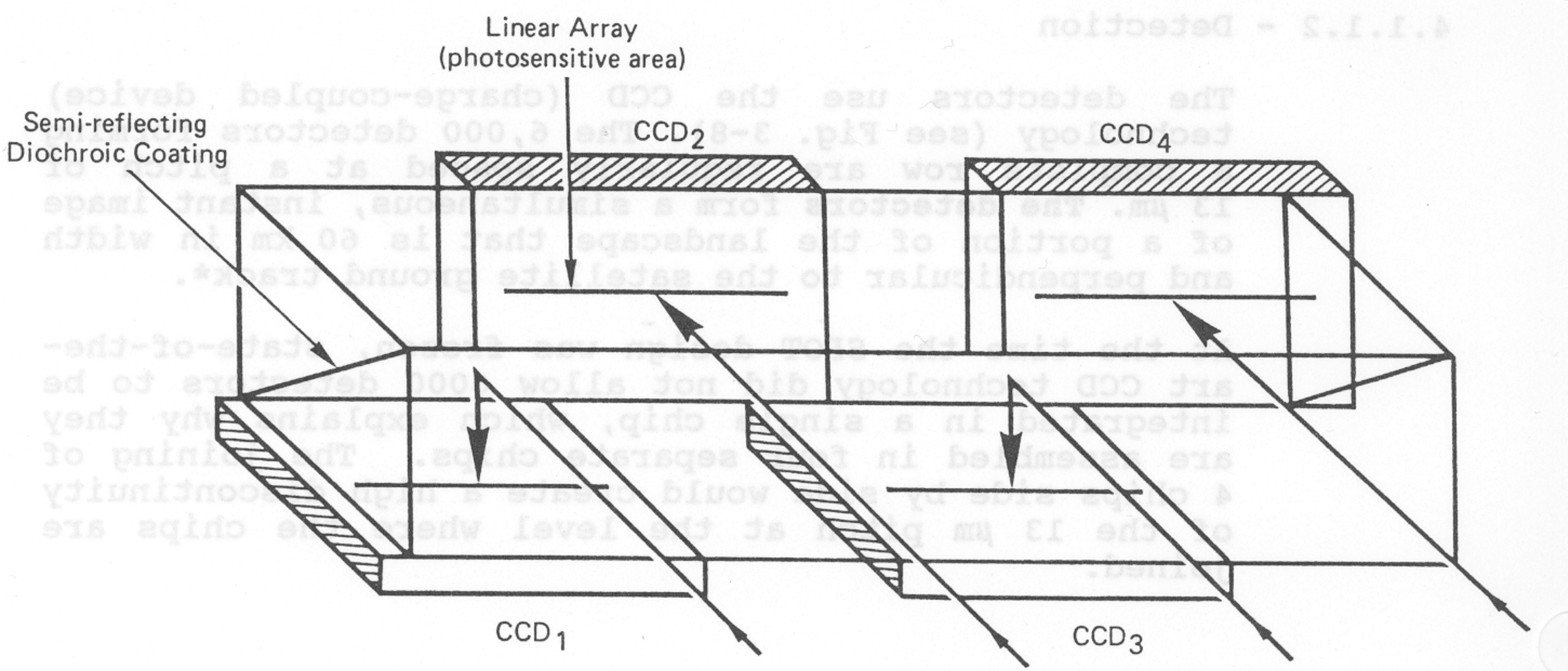


From Pease, Satellite Imaging Instruments

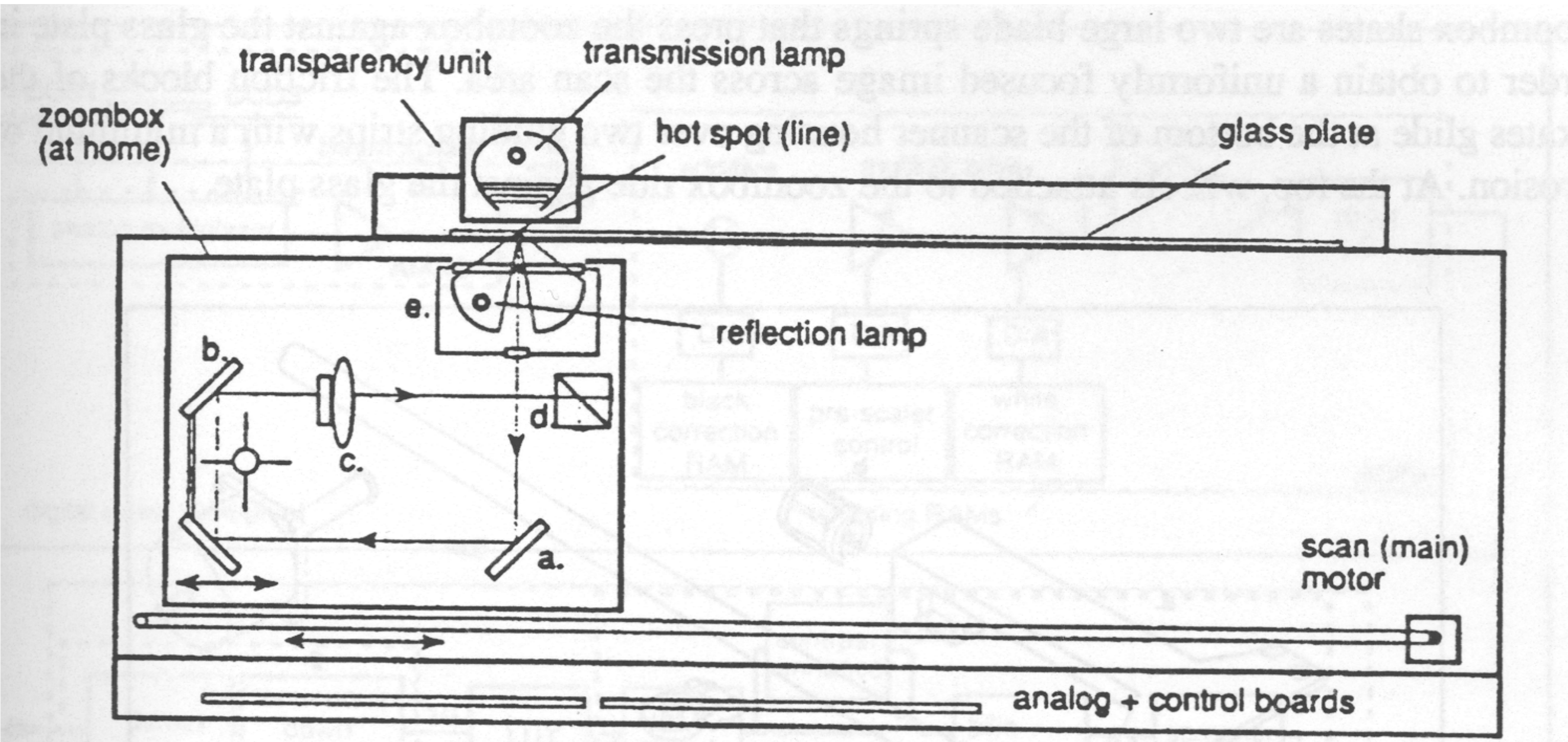
Spot – Detail of Detector Layout



Spot: Apparent 6000 pixel array from four 1500 pixel arrays



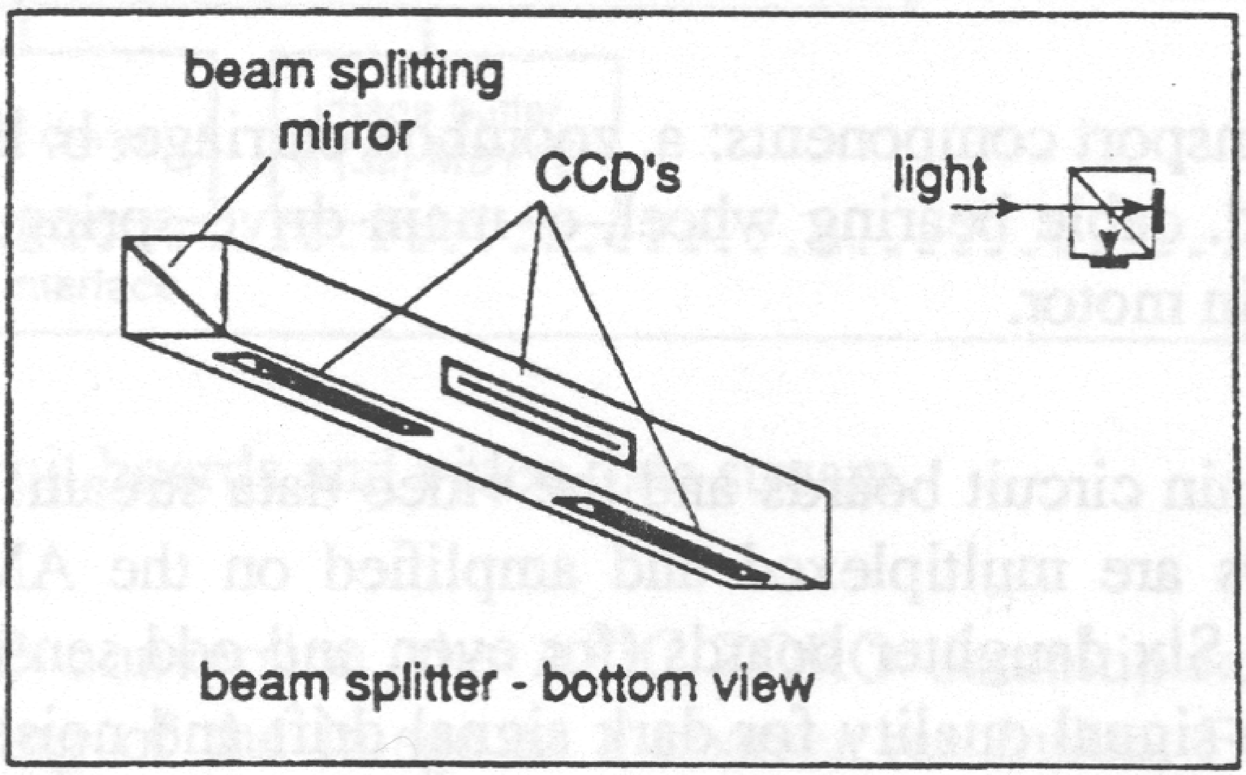
Desktop Scanner Architecture – Similar to Pushbroom



Approx. 10 year old Agfa machine, note color wheel (R,G,B) between a & b. This required multiple passes over the document. Other that size, there are many similarities to a pushbroom sensor.

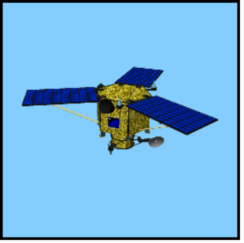
From Baltsavias, ISPRS Comm. I, 1993

“Optical Butting” Early Hi-res Scanners and Copiers Used Same Strategy as Spot



3 x 5000 element linear arrays produces an “apparent” length of 15000 elements. Today you could save a lot of money and get a single linear array (recall Kodak)

From Baltsavias, ISPRS Comm. I, 1993



Quickbird Focal Plane

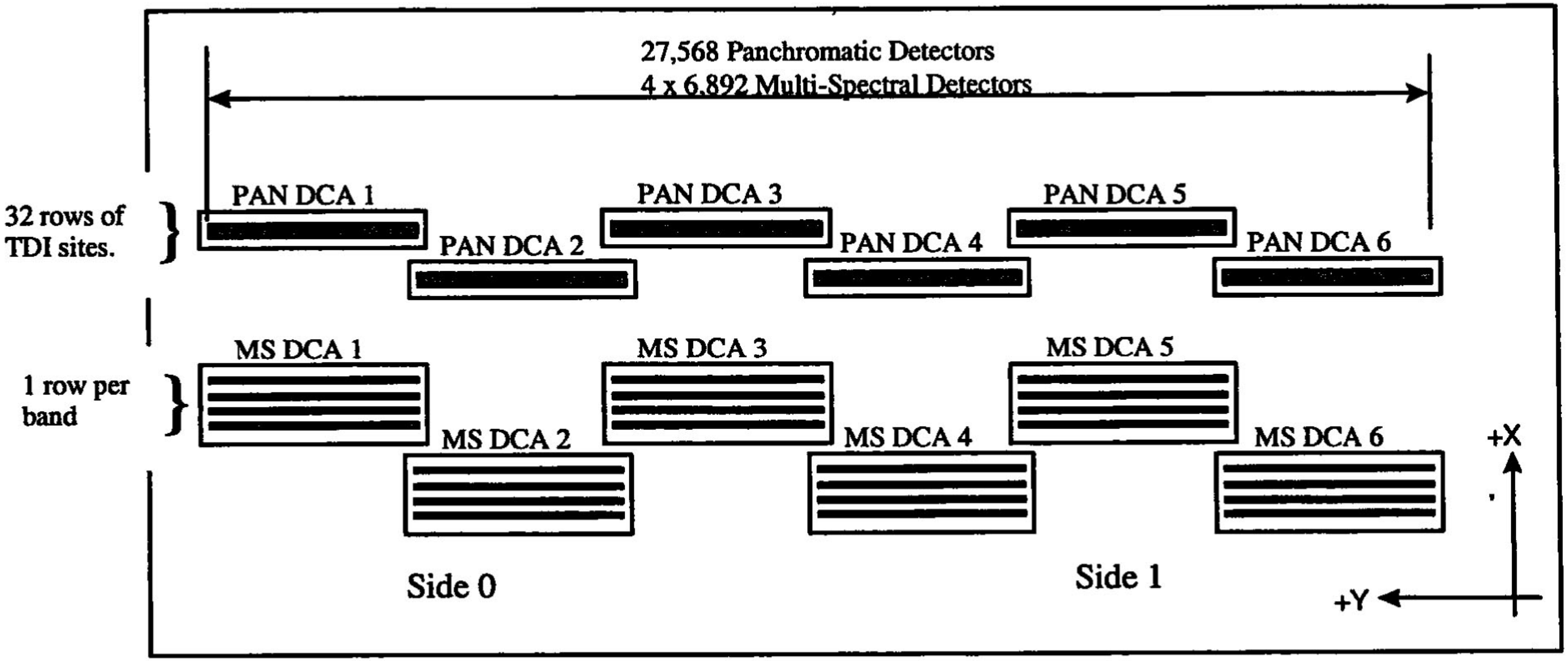
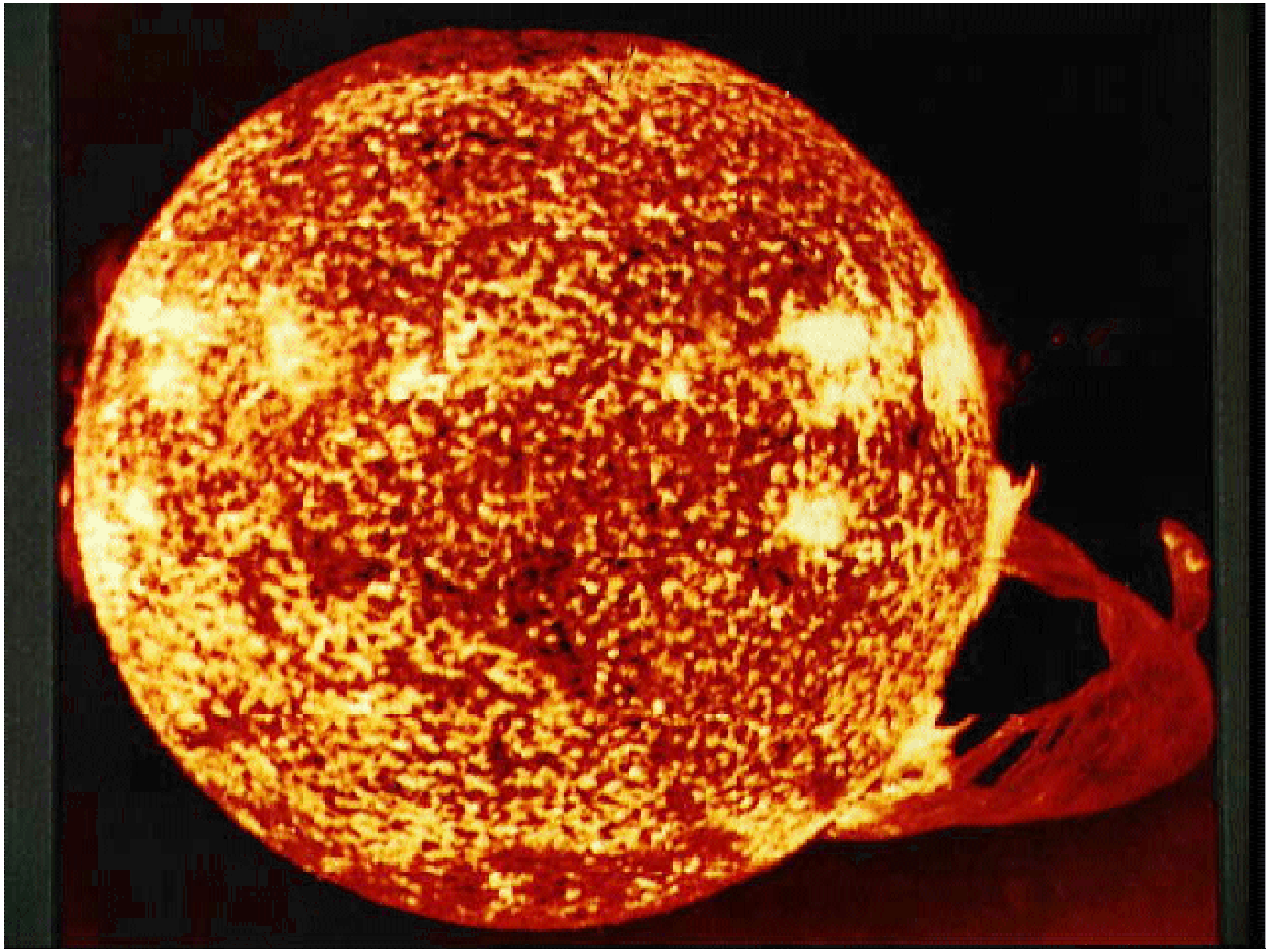
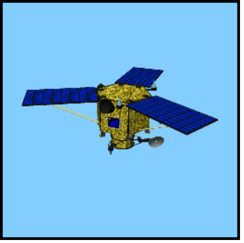


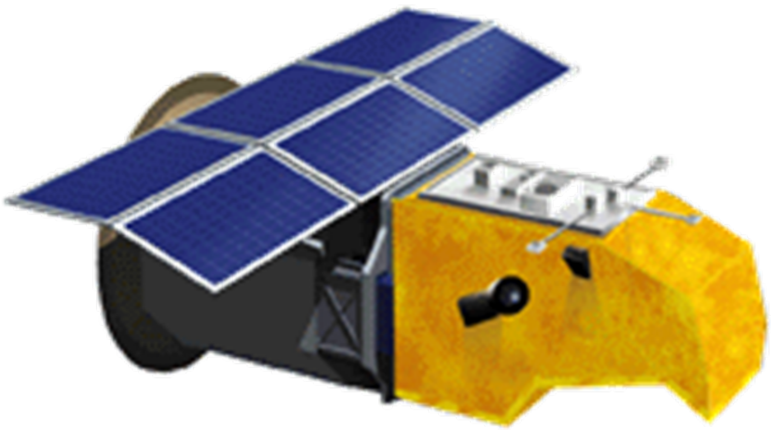
Figure 1: The QuickBird Focal Plane Layout (not drawn to scale)

Spot Attitude Control – Sun Tracker – Irregularities Lead to 0.2 Degree Accuracy

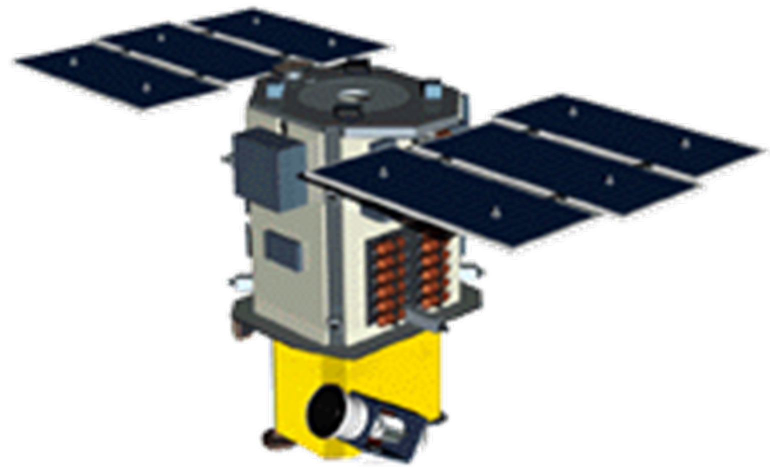




Digital Globe Projects

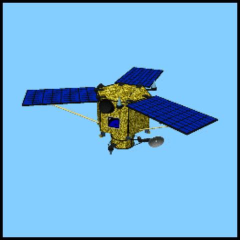


Earlybird (failed)



Quickbird

(Note Star tracker camera for attitude control)



Attitude Sensing

Quickbird Assembly

Star Tracking Camera CT-601 from Ball Aerospace

3 arc second accuracy

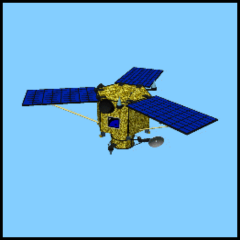
Compare

Spot: 0.2 deg @ 820 km => 2870m

Quickbird: 3 sec @ 450 km => 7m

Terrestrial Photograph of Orion

Assignment will be given next week to find attitude (orientation) of this photograph based on time of observation and tabulated star positions (apparent places). This will be done to emulate operation of a satellite star tracker – although it could be done independently for terrestrial camera calibration – no laboratory setup needed! – Another thought – feature extraction in general is difficult – here it works!



Alternative Laboratory Camera Calibration Apparatus

Reference points of known direction (or equivalently, location) can be used to determine internal camera parameters: focal length, principal point, lens distortion

Laboratory setup is most common, but stellar methods are very “doable” and they are cheap!, particularly for nonmetric, handheld cameras.

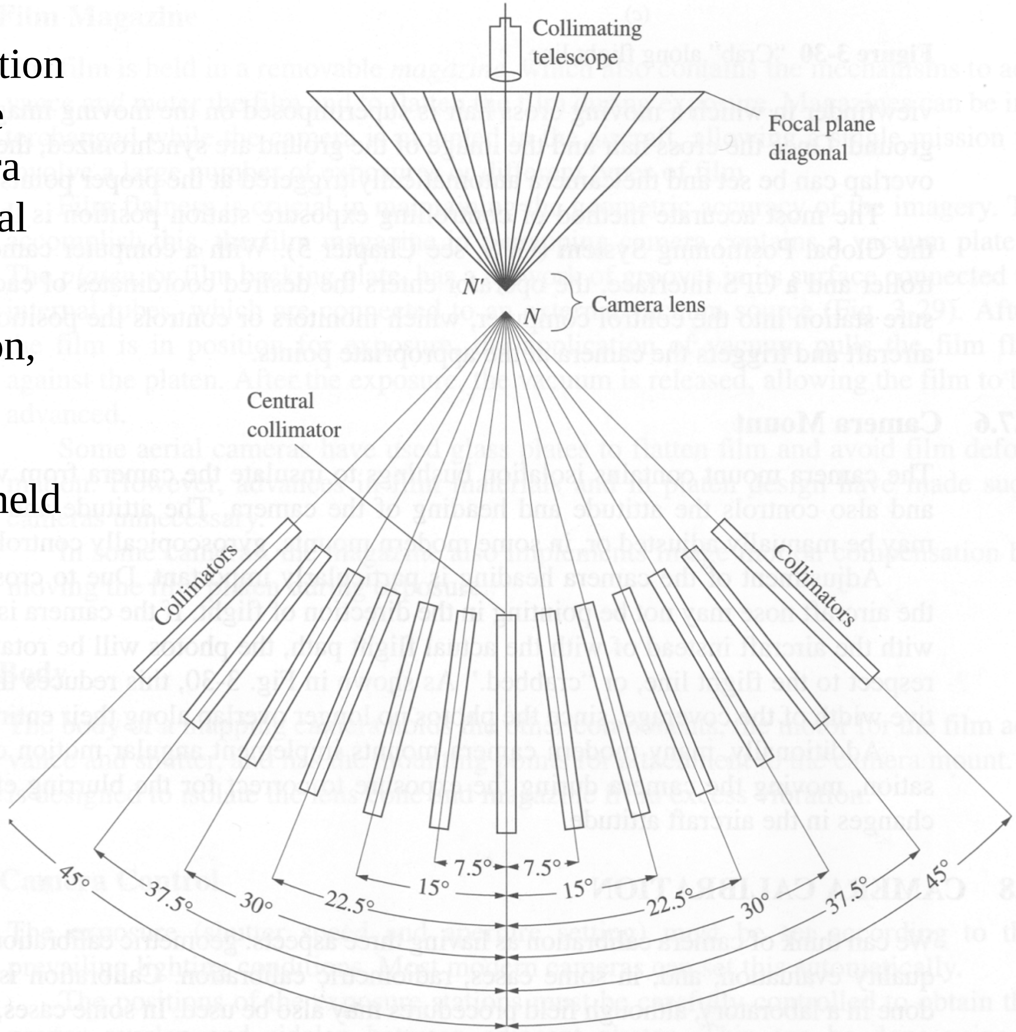
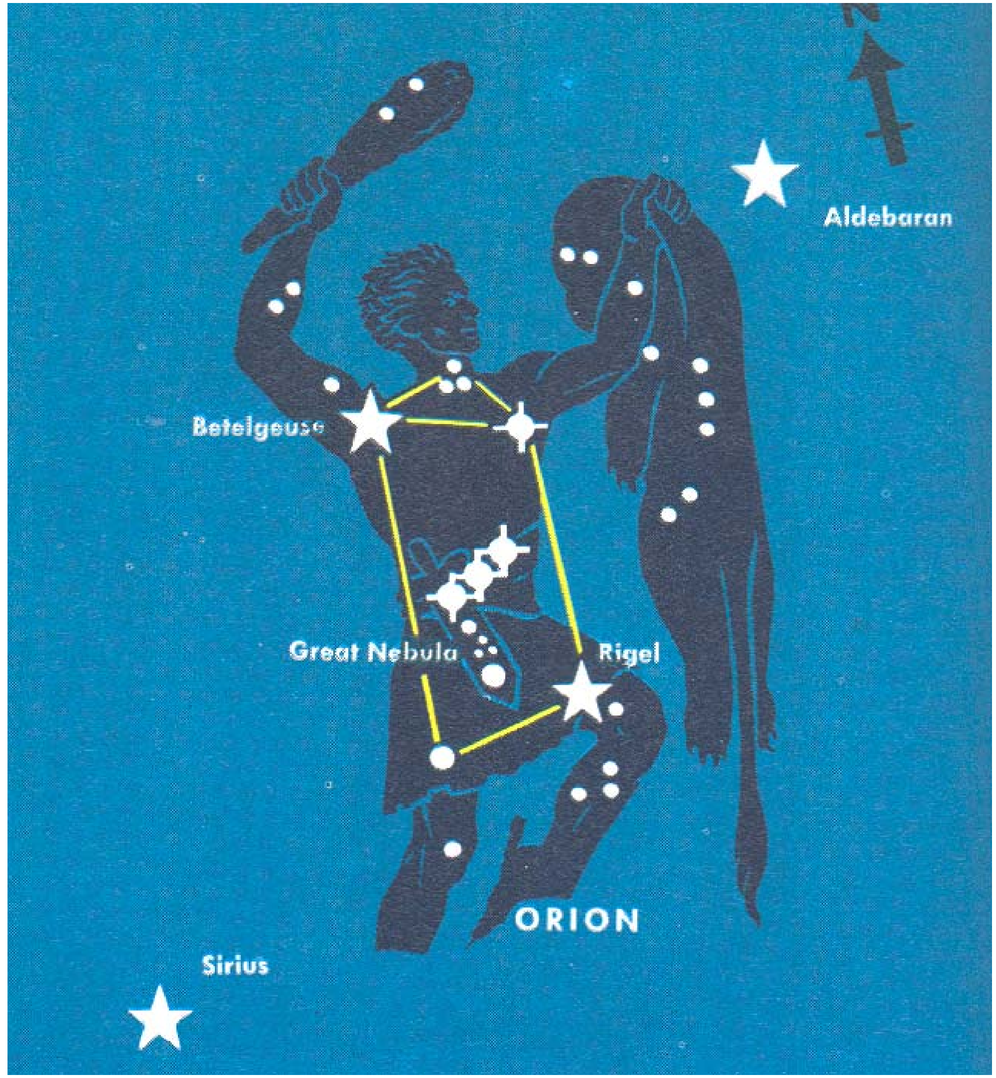


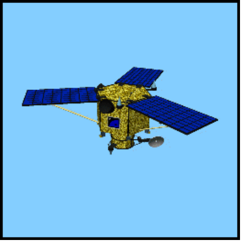
Figure 3-31 Schematic of a multicollimator for mapping camera calibration.

Constellation Orion, the Hunter

Betelgeuse: Red Supergiant, in the sword is M42, the great nebula, a mass of glowing gas 26 light years in diameter, 1625 light years away

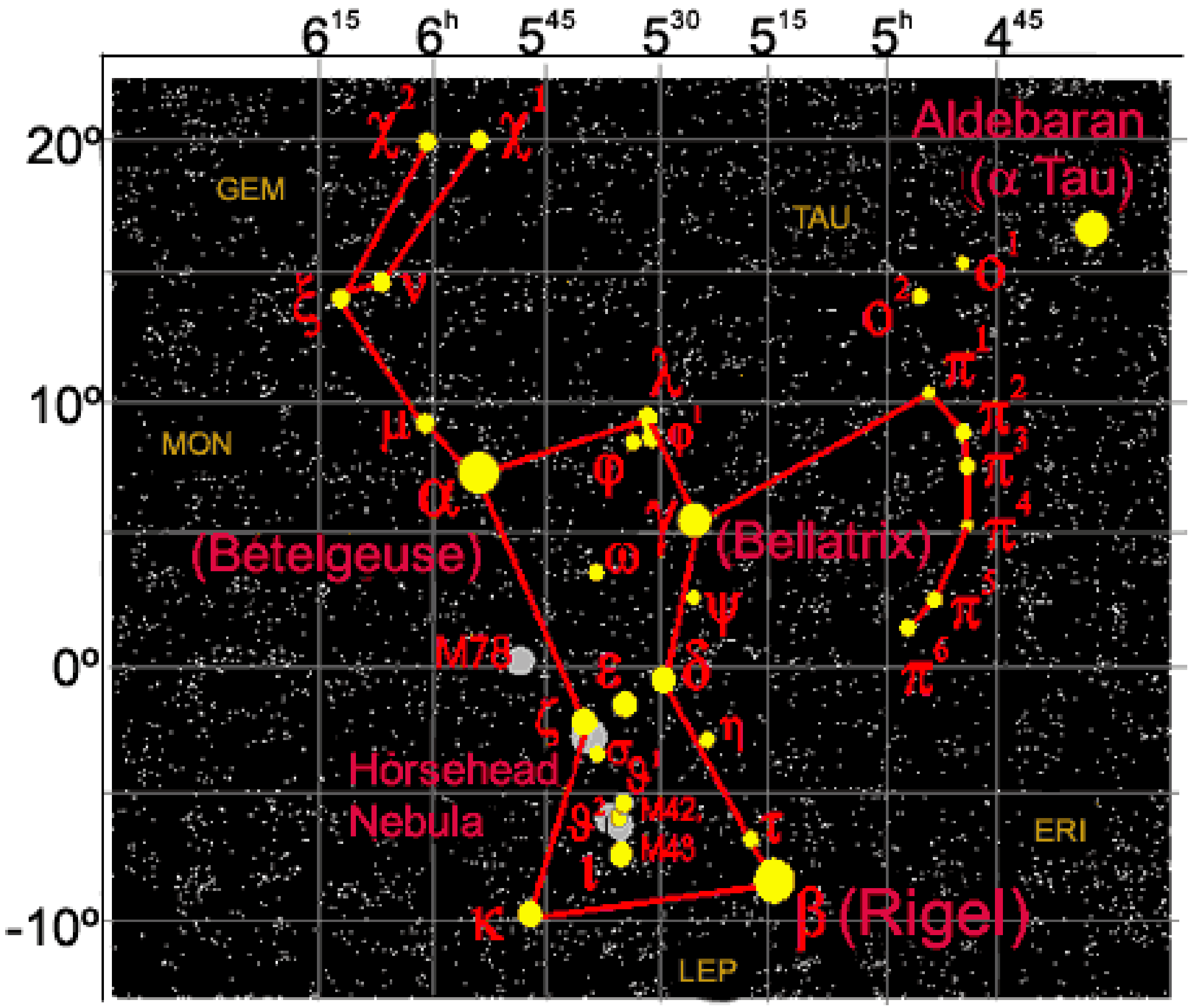


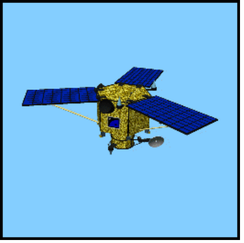
From Zim, Stars, Golden Guide



Orion

Right Ascension label is hours & minutes, declination label is degrees, Greek letters designate the major stars in the constellation, ranked (sort of) by magnitude, lesser magnitude stars get numbers

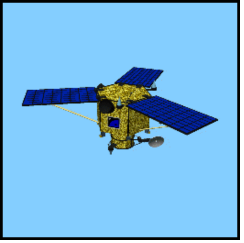




Orion Entries from Star Catalogue

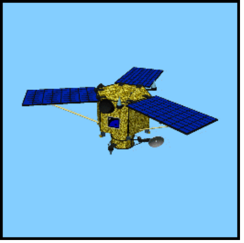
HR	Name	FK5	RA	DE	Vmag
---	---	---	h min s	deg arcmin arcsec	mag
1638	11 Ori	1140	05 04 34.1	+15 24 15	4.68
1662	13 Ori	-999	05 07 38.3	+09 28 19	6.17
1664	14 Ori	-999	05 07 52.9	+08 29 54	5.34
1672	16 Ori	1142	05 09 19.6	+09 49 46	5.43
1676	15 Ori	-999	05 09 42.0	+15 35 50	4.82
1698	17Rho Ori	-999	05 13 17.5	+02 51 40	4.46
1713	19Bet Ori	194	05 14 32.3	-08 12 06	0.12
1718	18 Ori	2395	05 16 04.1	+11 20 29	5.56
1735	20Tau Ori	195	05 17 36.4	-06 50 40	3.60
1746	21 Ori	-999	05 19 11.2	+02 35 45	5.34
1765	22 Ori	1147	05 21 45.7	-00 22 57	4.73
1770	23 Ori	-999	05 22 50.0	+03 32 40	5.00
1784	29 Ori	-999	05 23 56.8	-07 48 29	4.14
1787	27 Ori	-999	05 24 28.9	-00 53 29	5.08
1788	28Eta Ori	-999	05 24 28.6	-02 23 49	3.36
1789	25Psi1Ori	2406	05 24 44.8	+01 50 47	4.95
1790	24Gam Ori	201	05 25 07.9	+06 20 59	1.64
1811	30Psi2Ori	-999	05 26 50.2	+03 05 44	4.59
1834	31 Ori	-999	05 29 44.0	-01 05 32	4.71
1839	32 Ori	-999	05 30 47.1	+05 56 53	4.20
1842	33 Ori	-999	05 31 14.5	+03 17 32	5.46
1851	34Del Ori	-999	05 32 00.5	-00 17 04	6.85
1852	34Del Ori	206	05 32 00.4	-00 17 57	2.23
1855	36Ups Ori	-999	05 31 55.8	-07 18 05	4.62
1864	35 Ori	2414	05 33 54.3	+14 18 20	5.64
1872	38 Ori	-999	05 34 16.7	+03 46 01	5.36

Excerpt from star catalogue, used to be only printed by government organizations – now you can find it on the web



Orion Star Catalogue cont'd

1879	39Lam	Ori	-999	05 35 08.3	+09 56 03	3.54
1880	39Lam	Ori	-999	05 35 08.5	+09 56 06	5.61
1892	42	Ori	-999	05 35 23.2	-04 50 18	4.59
1893	41The1	Ori	-999	05 35 15.9	-05 23 14	6.73
1894	41The1	Ori	-999	05 35 16.1	-05 23 07	7.96
1895	41The1	Ori	-999	05 35 16.5	-05 23 23	5.13
1896	41The1	Ori	-999	05 35 17.3	-05 23 16	6.70
1897	43The2	Ori	-999	05 35 22.9	-05 24 58	5.08
1899	44Iot	Ori	209	05 35 26.0	-05 54 36	2.77
1901	45	Ori	-999	05 35 39.5	-04 51 21	5.26
1903	46Eps	Ori	210	05 36 12.8	-01 12 07	1.70
1907	40Phi2	Ori	-999	05 36 54.3	+09 17 26	4.09
1931	48Sig	Ori	-999	05 38 44.8	-02 36 00	3.81
1934	47Ome	Ori	2423	05 39 11.1	+04 07 17	4.57
1937	49	Ori	-999	05 38 53.1	-07 12 47	4.80
1948	50Zet	Ori	-999	05 40 45.5	-01 56 34	2.05
1949	50Zet	Ori	-999	05 40 45.6	-01 56 34	4.21
1963	51	Ori	2427	05 42 28.6	+01 28 29	4.91
1999	52	Ori	-999	05 48 00.2	+06 27 15	5.27
2004	53Kap	Ori	220	05 47 45.4	-09 40 11	2.06
2031	55	Ori	2442	05 51 22.0	-07 31 05	5.35
2037	56	Ori	2444	05 52 26.4	+01 51 18	4.78
2047	54Chi1	Ori	-999	05 54 22.9	+20 16 34	4.41
2052	57	Ori	2447	05 54 56.7	+19 44 59	5.92
2061	58Alp	Ori	224	05 55 10.3	+07 24 25	0.50
2100	59	Ori	-999	05 58 24.4	+01 50 13	5.90
2103	60	Ori	1161	05 58 49.6	+00 33 11	5.22



Fundamental Imaging Equations of Photogrammetry: The Collinearity Equations

Lower case variables on the left are in image space. Upper case variables on the right are in object space. Matrix ***M*** relates the object and images space coordinate systems.

See chapter 4 of the text for derivation and explanation.

If we divide the vector components on the right by the vector length – we get direction cosines – better for objects *very* far away.

$$\begin{bmatrix} x - x_0 \\ y - y_0 \\ -f \end{bmatrix} = kM \begin{bmatrix} X - X_L \\ Y - Y_L \\ Z - Z_L \end{bmatrix} \quad (4\text{-}21)$$

The matrix M can be expressed in terms of its elements:

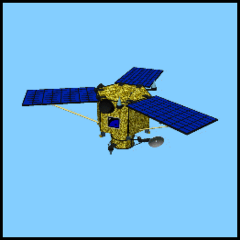
$$\begin{bmatrix} x - x_0 \\ y - y_0 \\ -f \end{bmatrix} = k \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \begin{bmatrix} X - X_L \\ Y - Y_L \\ Z - Z_L \end{bmatrix} \quad (4\text{-}22)$$

Multiplying the matrix and vector on the right-hand side of the equation, we obtain three scalar equations instead of a matrix equation:

$$\begin{aligned} x - x_0 &= k[m_{11}(X - X_L) + m_{12}(Y - Y_L) + m_{13}(Z - Z_L)] \\ y - y_0 &= k[m_{21}(X - X_L) + m_{22}(Y - Y_L) + m_{23}(Z - Z_L)] \\ -f &= k[m_{31}(X - X_L) + m_{32}(Y - Y_L) + m_{33}(Z - Z_L)] \end{aligned} \quad (4\text{-}23)$$

The scale factor is something of a nuisance parameter and can be eliminated by dividing the first two equations in 4-23 by the third to obtain the classical form of the collinearity equations:

$$\begin{aligned} x - x_0 &= -f\,\frac{m_{11}(X - X_L) + m_{12}(Y - Y_L) + m_{13}(Z - Z_L)}{m_{31}(X - X_L) + m_{32}(Y - Y_L) + m_{33}(Z - Z_L)} \\ y - y_0 &= -f\,\frac{m_{21}(X - X_L) + m_{22}(Y - Y_L) + m_{23}(Z - Z_L)}{m_{31}(X - X_L) + m_{32}(Y - Y_L) + m_{33}(Z - Z_L)} \end{aligned} \quad (4\text{-}24)$$



Stellar Version of Collinearity

$$x - x_0 = -f\frac{m_{11}C_x + m_{12}C_y + m_{13}C_z}{m_{31}C_x + m_{32}C_y + m_{33}C_z}$$

$$y - y_0 = -f\frac{m_{21}C_x + m_{22}C_y + m_{23}C_z}{m_{31}C_x + m_{32}C_y + m_{33}C_z}$$

Object point coordinates and exposure station coordinates have been replaced by direction cosines.

See chapter 4.

$$\begin{bmatrix} C_x \\ C_y \\ C_z \end{bmatrix} = \begin{bmatrix} \cos\alpha\cos\delta \\ \sin\alpha\cos\delta \\ \sin\delta \end{bmatrix}$$

and α and δ are the right ascension and declination of the star, respectively.

You can work directly in right ascension and declination, but terrestrial applications are more likely to work in azimuth and declination, so we can correct for atmospheric refraction, etc. To transform beween the two we need location and time.