Analysis of UVOT Data: short tutorial

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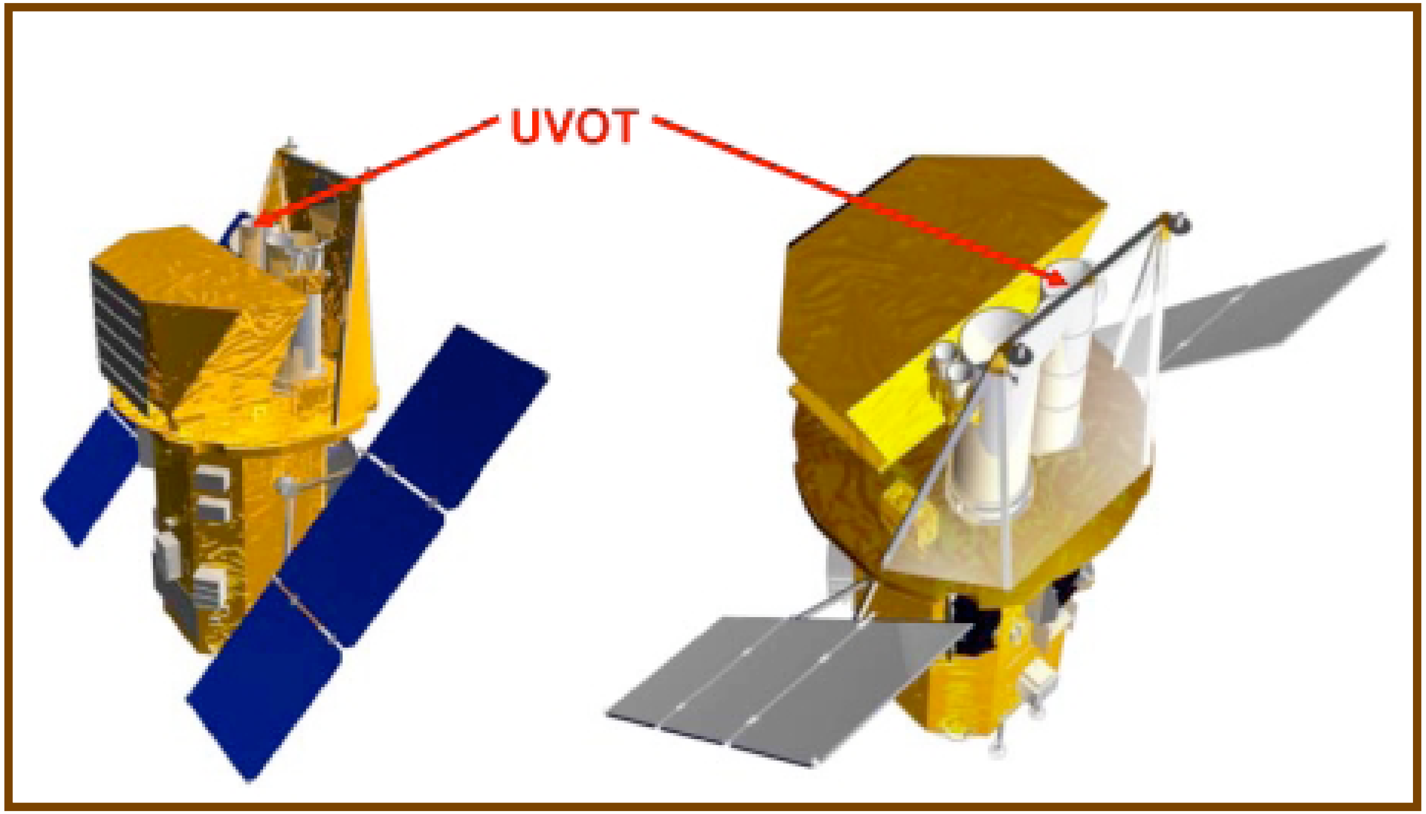
Outline

- The UVOT instrument
    - Optical Layout, CCD, filters (only photometry)
- Data Products
- Aperture Photometry
    - Calibration
    - Standard FTOOLS
- Example

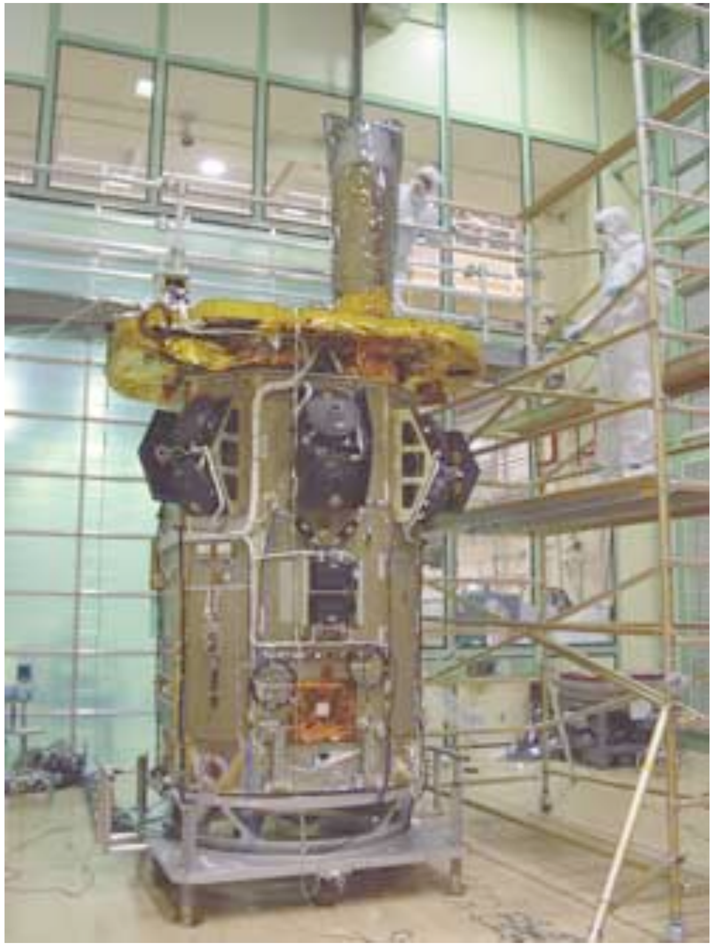
UVOT



Technical paper

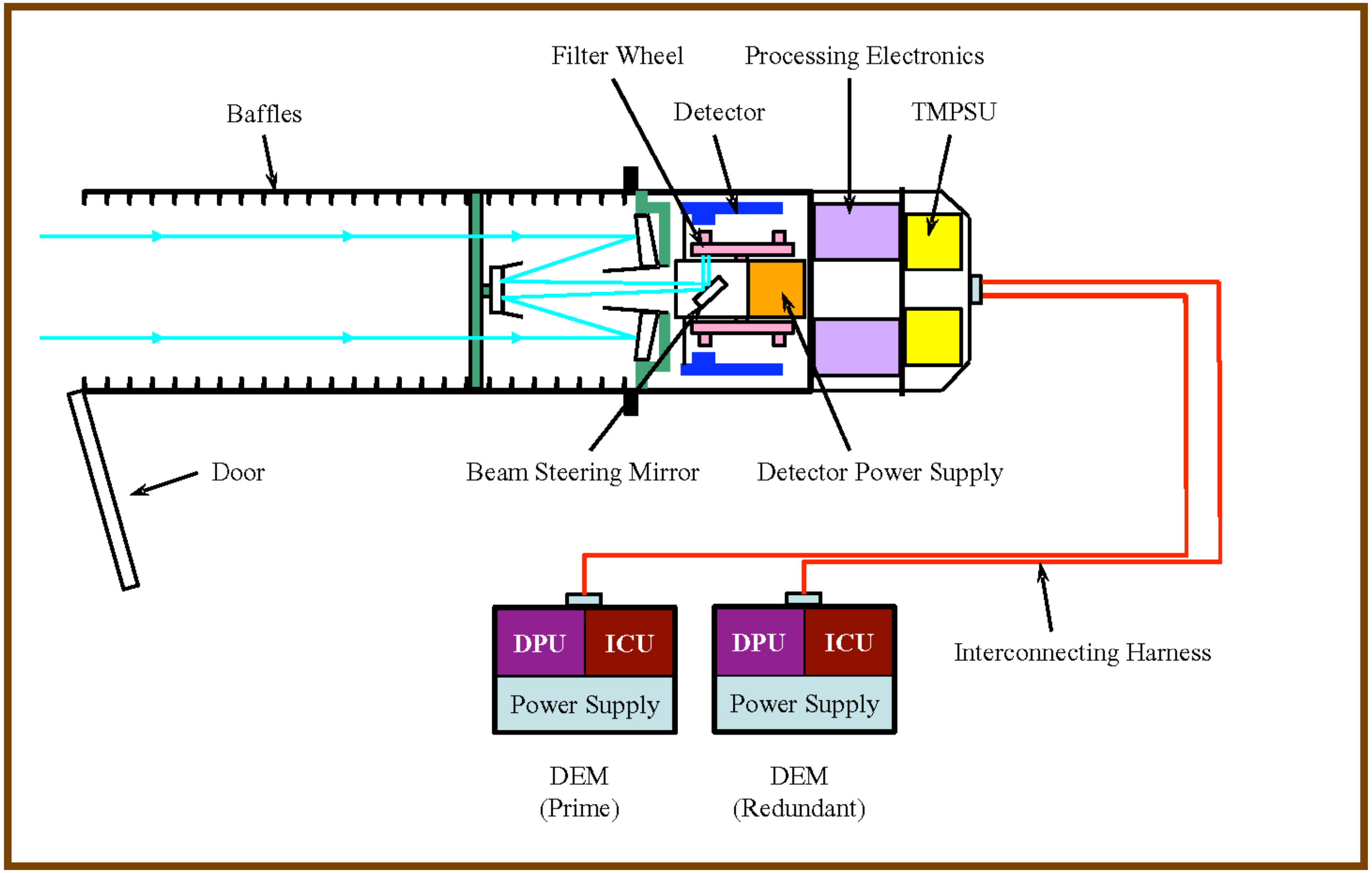
Roming et al. Space Science Reviews (2005) 120: 95–142

UVOT Characteristics

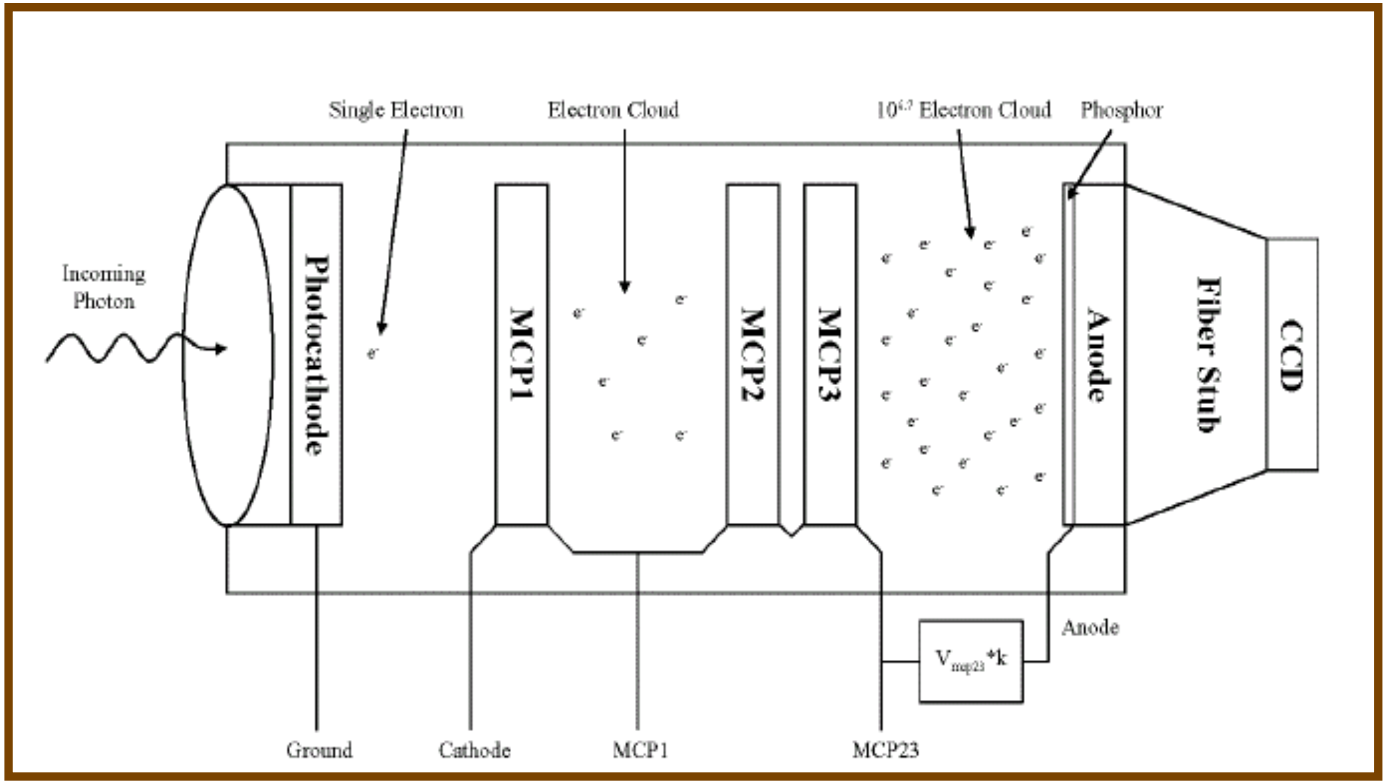


Telescope	Modified Ritchey-Chrétien
Aperture	30 cm diameter
f-number	12.7
Filters	11
Wavelength Range	170-600 nm
Detector	MCP Intensified CCD
Detector Operation	Photon Counting
Sensitivity	m_B=24.0 in white light in 1000s
Field of View	17 x 17 arcmin^2
Detection Element	256 x 256 pixels
Sampling Element	2048 x 2048 after centroiding
Telescope PSF	0.9 arcsec FWHM @ 350nm
Pixel Scale	0.5 arcsec

UVOT

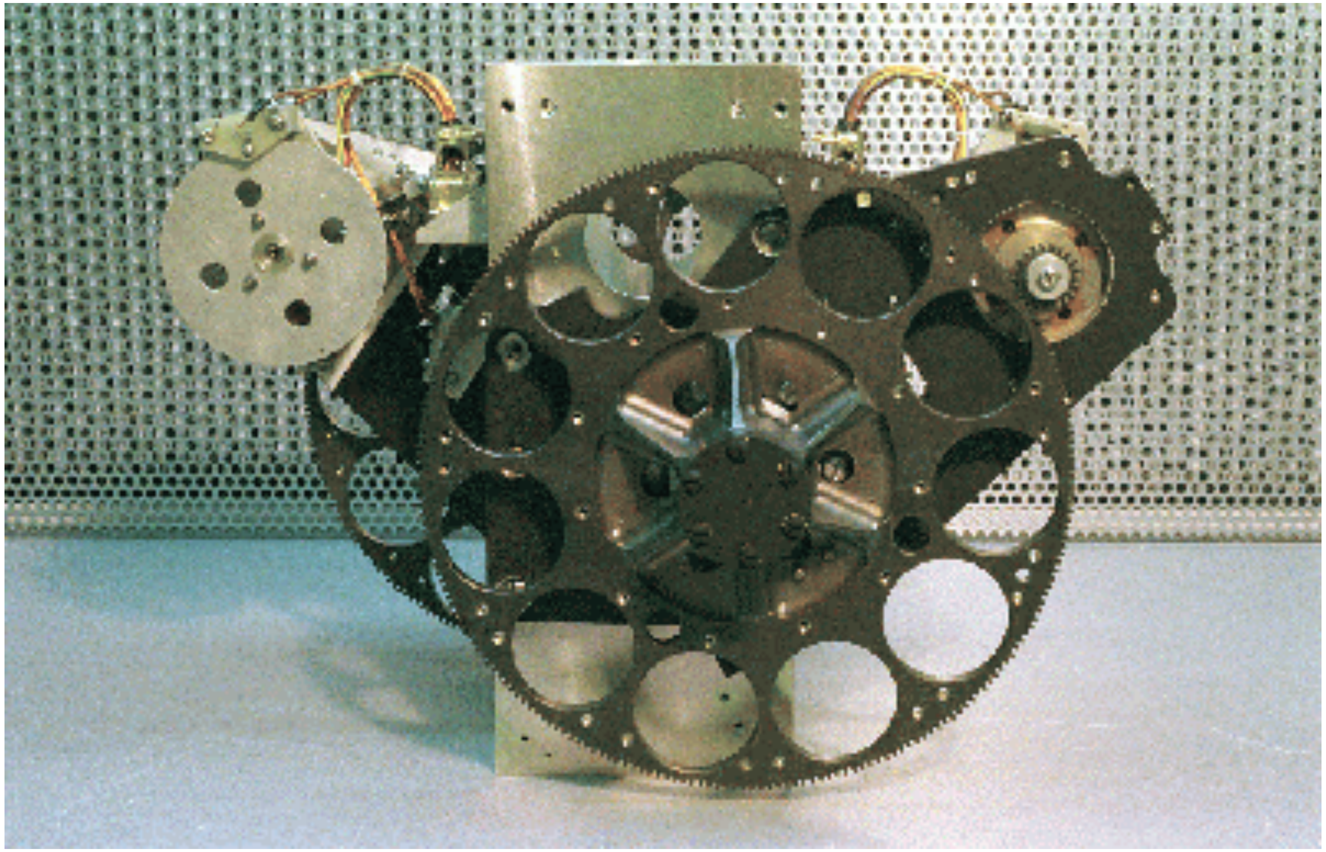

Filter Wheel
Processing Electronics
Baffles
Detector
TMPSU
Door
Beam Steering Mirror
Detector Power Supply
DPU
ICU
Power Supply
DPU
ICU
Power Supply
Interconnecting Harness
DEM
(Prime)
DEM
(Redundant)

UVOT



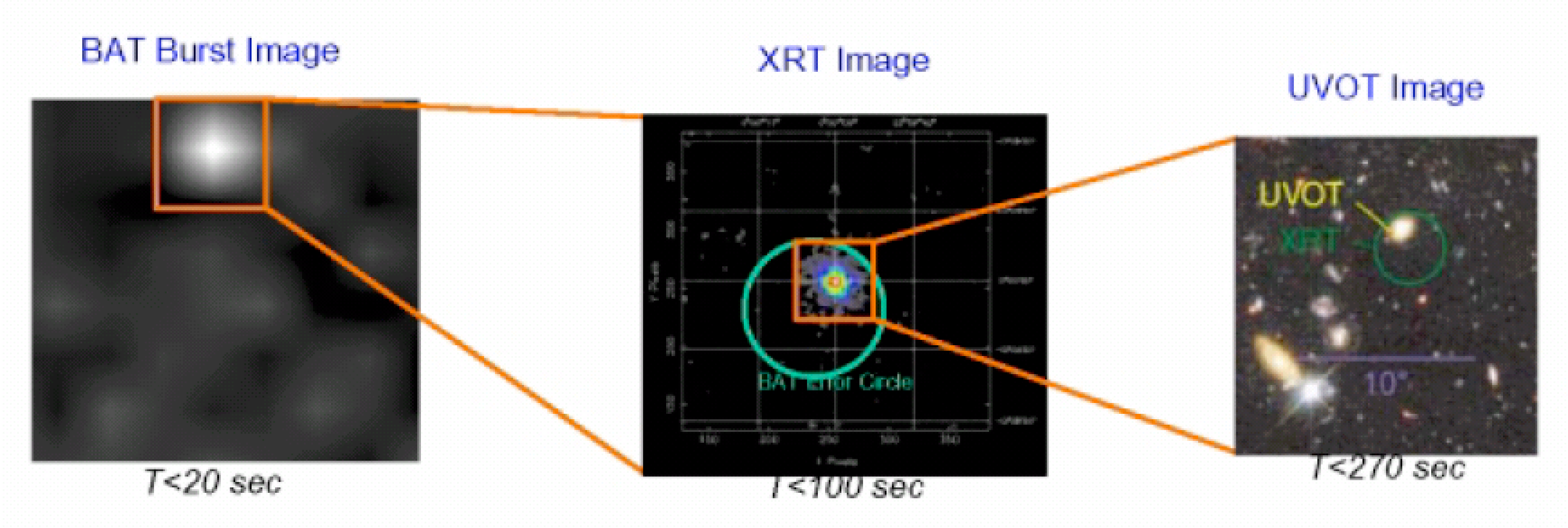
MCP(micro-channel plate) **intensified CCD**

UVOT Filter Weels



11 position filter wheel

UVOT FOV (17’x17’)

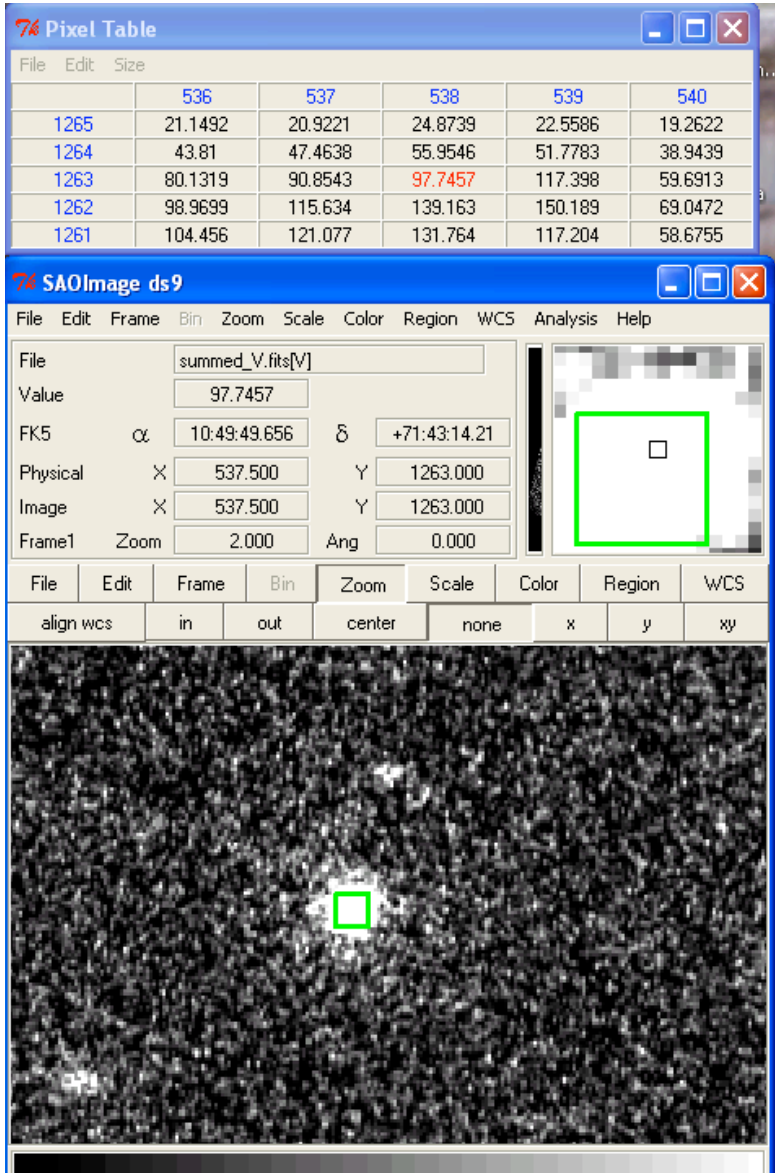


m101

CCD Photometry References

- “Astronomical CCD Observing and Reduction Techniques”, S. B. Howell, ed., 1992, *ASP Conf. Series* 23.
- Stetson, P. 1990, *PASP* 102, 932.
- DaCosta, G., 1992, *ASP Conf. Series* 23, 90.
- S. Howell, “Handbook of CCD Astronomy”, Cambridge Univ. Press (2000)
- G. Walker, “Observational Astronomy”, Cambridge Univ. Press (1987), Ch. 7.
- M. Newberry 1991, PASP, 102, 122

CCD Photometry

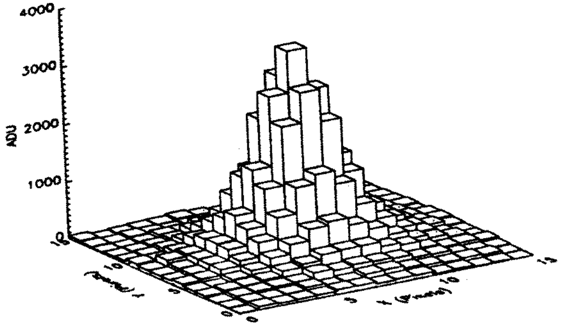


- Components of the CCD signal
  - S = measured signal in a pixel
  - Ro = rate (photons/sec) of desired signal
  - t = exposure time of Ro
  - q = responsive quantum efficiency
  - s = shadowing due to dust, etc. on filter, window, …
  - V = vignetting in optics
  - Rd = dark count rate (thermal)
  - B = bias charge on each pixel

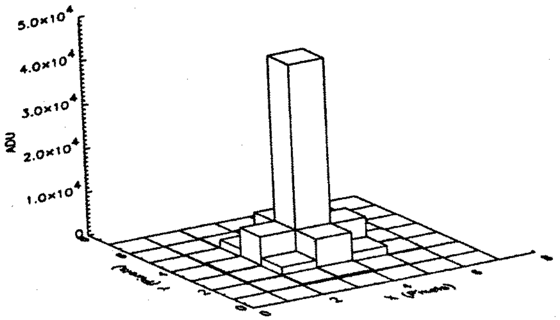
Components of the Signal

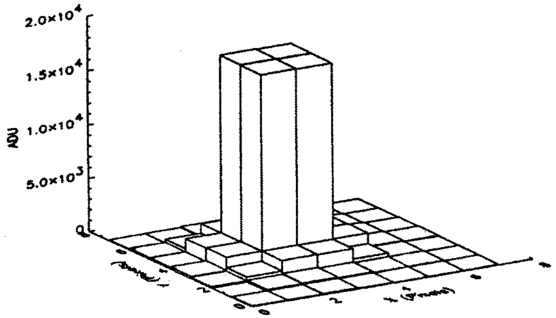
- The equation for *each* pixel:
  - $S = [V*s*q]*(R_o*t) + R_d*t_d + B$
  - We want R_o, the photon rate of the target!
    - Flat field = [V*s*q]
      - Usually dominated by the pixel-to-pixel variation in the responsive quantum efficiency - typically +/- several %
    - Dark current = R_d*t_d
      - Thermally induced. Exp. Time since the last read cycle, can have pixel-to-pixel variations of several %
    - Bias = B (normally has two components)
      - Bs = structure bias, which is usually a constant due to the camera electronics.
      - Bo = offset bias, which tends to change with time
      - R = read-out noise

Image PSF



Well sampled stars: ideal case





Badly undersampled. Star profile strongly depends on the position of the center within the central pixel. The problem is worsened by the intra-pixel sensibility variation.

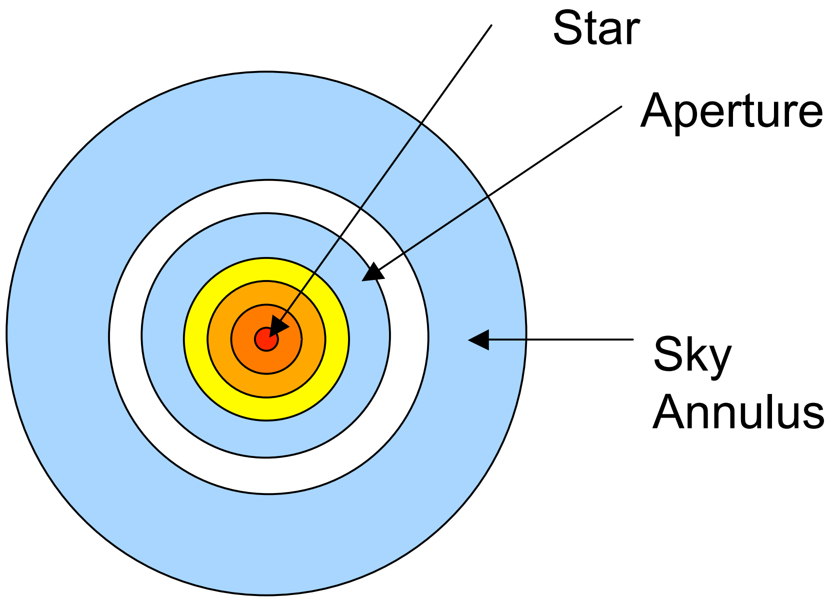
PSF Photometry

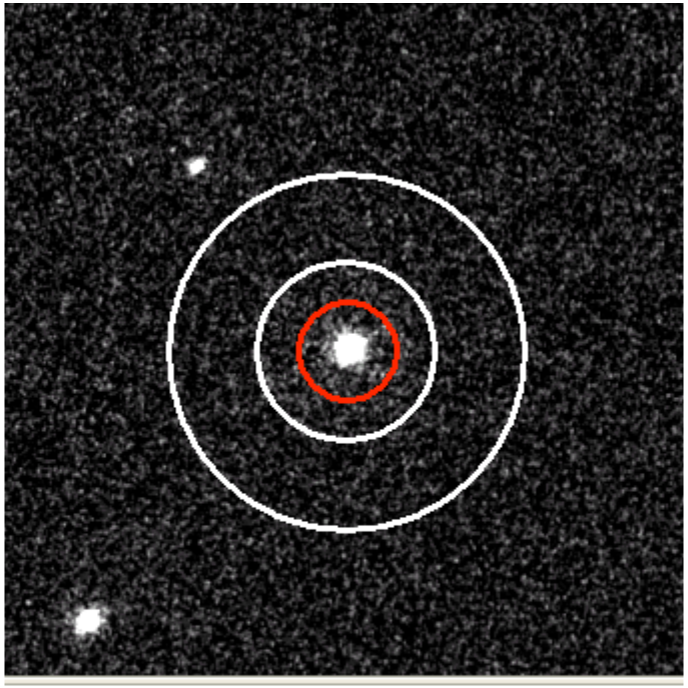
- The stellar profile is (first approx.) a Gaussian core:
  - $G(x) = (\sigma_x \sqrt{2\pi})^{-1} \exp-\{0.5[(x - x_c)/\sigma_x]^2\}$
    - $\int_x G(x) = 1.0$
    - $G(x = x_c) = 0.3989$
    - $G(x = x_c \pm \sigma_x) = 0.2420$: 0.607 height at $x = x_c$
    - $G(x = x_c \pm \text{fwhm}/2) = 0.1995$: one-half the height at $x = x_c$
  - Gaussian doesn't fit in wings, so other functions are added
    - Modified Lorentzian: $L(x) = C^*\{1 + (x^2/\sigma^2)^{ß}\}^{-1}$
    - Moffat function: $M(x) = C^*\{1 + (x^2/\sigma^2)\}^{-ß}$
      - C = constant
  - Not even those are perfect so a table of corrections (H(x,y) is added to give the final model PSF:
    - $PSF(x,y) = [a^*G(x,y) + b^*L(x,y) + c^*M(x,y)] * [1 + H(x,y)]$
    - DAOPHOT and IRAF: See Stetson, P. in PASP **102**, 932, 1990.

Aperture Photometry

- It is the most accurate flux measurement, for non-crowded images
- Select an aperture of radius **r** that contains the image and sum all of the pixels that fall within the aperture
  - $I_{sum} = I_* + <B>$
  - What radius should be used to include all of the stellar flux?
    - PSF Analysis
    - Grow curves analysis
  - What about the sky within the aperture?

Aperture Photometry





$$m = zpt - 2.5 log I$$

Signal in aperture: Star + aperture_area x sky_average

Signal in Annulus: annulus_area x sky_average

Signal of Star: aperture_signal – aperture_area x sky_average

Background evaluation

A good estimate of the local sky brightness is the mode of the distribution of the pixel counts in an annular aperture around the stars. Poisson errors make the peak of the histogram rather messy.

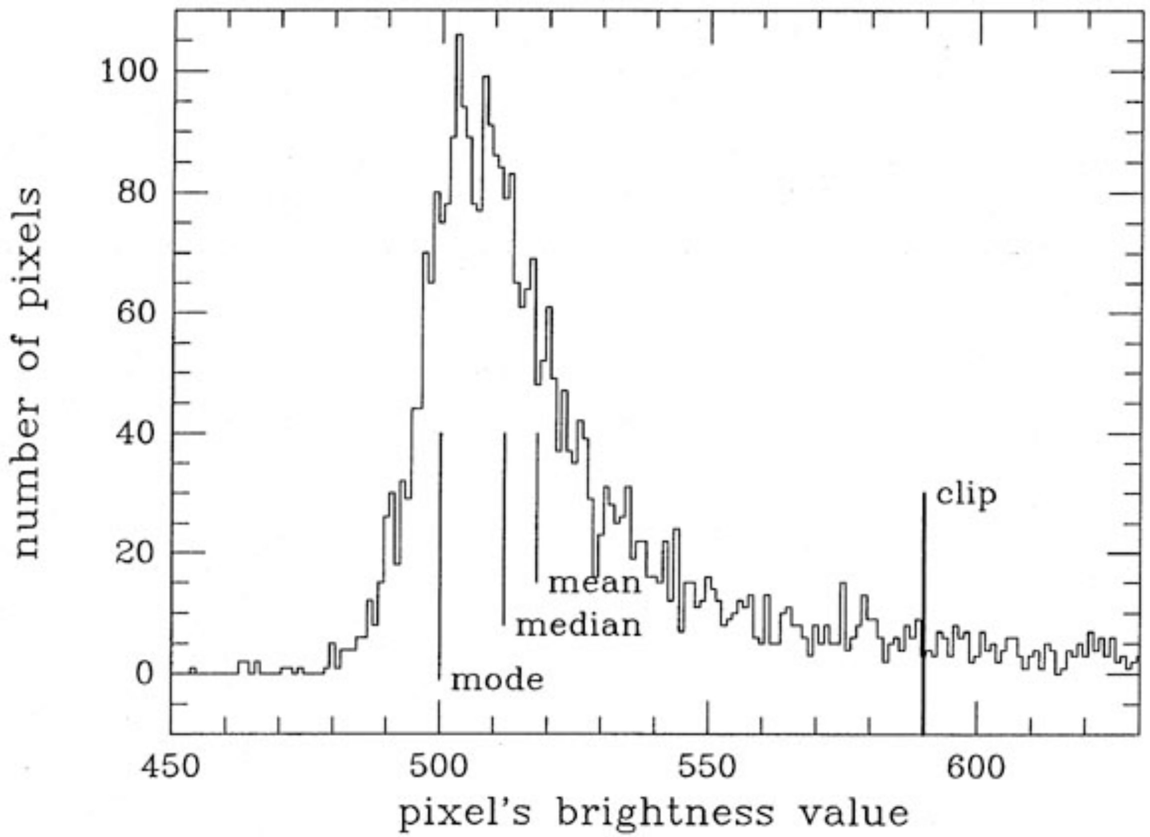


Image Centers, Centroids etc

- The **Centroid , center of mass** or **1st moment** of the distribution.
  - $<x> = \sum_{x,y}\{x_i*[I(x,y) - B]\} / \sum_{x,y}[I(x,y) - B]$,
  - $<y> = \sum_{x,y}\{y_i*[I(x,y) - B]\} / \sum_{x,y}[I(x,y) - B]$
    - The centroid is very sensitive to the adopted sky background, but it is also works well for very faint images.

- The **Image Center**
  - Auer and van Altena: AJ 83, 531, 1978 and Stetson in DAOPHOT manuals.
  - The Marginal distributions are defined by:
    - $\rho_x(x) = N_y^{-1}\sum_y I_o(x,y)$ (N_y =integral of the distribution)
    - $\rho_y(y) = N_x^{-1}\sum_x I_o(x,y)$

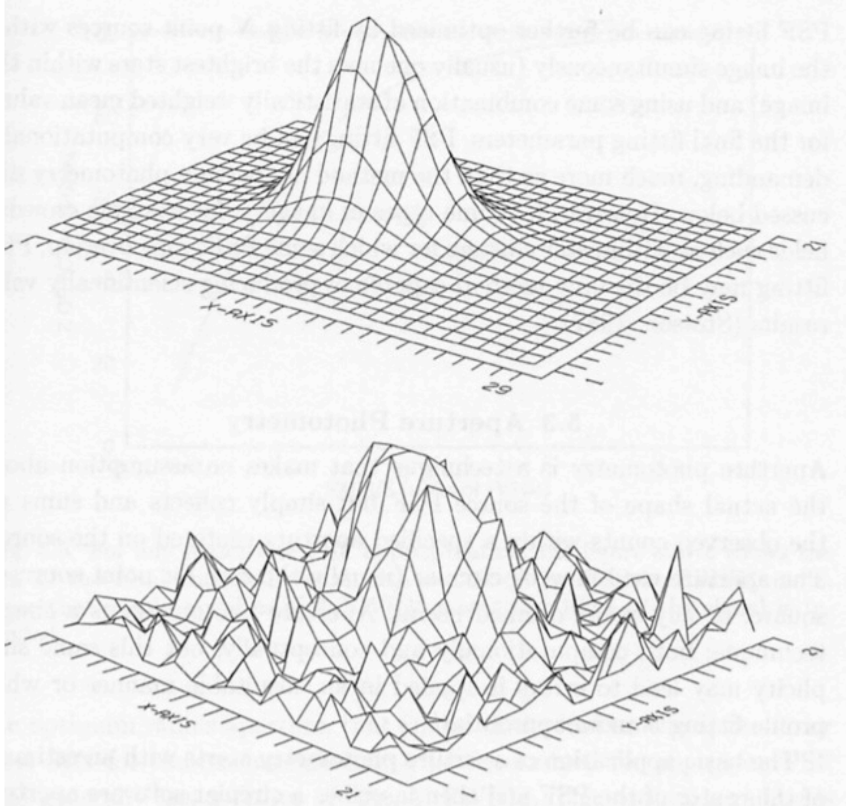
    Fit the maginal distribution with:

$$\rho_x(x) = a_x + h_x \exp(-0.5((x-x_c) / R_x)^2)$$

Image Centers, Centroids etc

- **The Bivariate Gaussian**
  - Lee and van Altena: AJ 88, 1683, 1983
  - D_o = image height at center
  - $r^2 = (x-x_c)^2 + (y-y_c)^2$
  - R = Gaussian radius
  - B = background
- Precision
  - #1 Bivariate
  - #2 Univariate
  - #3 Centroid

•$F(x,y) = D_o \exp(-0.5r^2 / R^2) + B$



However the centroid is most stable, especially for faint images.

Magnitude

$$m_\lambda = -2.5 log F_\lambda + F_\lambda^0$$

Standard U, B, V, R, I and long wavelength systems

Filter band	λ_0[(a)] (μm)	$\Delta\lambda_0$ (FWHM) (μm)	Absolute spectral irradiance for mag = 0.0: $f_\lambda(0)$ (erg cm^{-2} s^{-1} Å^{-1})	$f_\nu(0)$ (W m^{-2} Hz^{-1})
U	0.365	0.068	4.27×10^{-9}	1.90×10^{-23}
B	0.44	0.098	6.61×10^{-9}	4.27(4.64)[(b)] $\times 10^{-23}$
V	0.55	0.089	3.64×10^{-9}	3.67×10^{-23}
R	0.70	0.22	1.74×10^{-9}	2.84×10^{-23}
I	0.90	0.24	8.32×10^{-10}	2.25×10^{-23}
J	1.25	0.3	3.18×10^{-10}	1.65×10^{-23}
H	1.65	0.4	1.18×10^{-10}	1.07×10^{-23}
K	2.2	0.6	4.17×10^{-11}	6.73×10^{-24}
L	3.6	1.2	6.23×10^{-12}	2.69×10^{-24}
M	4.8	0.8	2.07×10^{-12}	1.58×10^{-24}
N	10.2		1.23×10^{-13}	4.26×10^{-25}

[(a)] $\lambda_0 = \int \lambda S(\lambda)\,d\lambda / \int S(\lambda)\,d\lambda$, where $S(\lambda)$ is the photometer response function.
[(b)] From S. Kleinmann.
U, B, R, I, N values from Allen, C. W., *Astrophysical Quantities*. The Athlone Press (1973). *V, J, H, K, L, M* values from Wamsteker, W., *Astron. Astrophys.*, **97**, 329 (1981).

IMS Extinction

Interstellar reddening

The observed color index is given by

$$C_{ij} = C_{ij}^0 + [A(\lambda_i) - A(\lambda_j)] \equiv C_{ij}^0 + E_{ij},$$

where

$A(\lambda) =$ amount of interstellar absorption at λ,
$C_{ij}^0 =$ intrinsic color index of the star,
$E_{ij} \equiv$ color excess.

In the UBV system, the color excesses are

$$E(B-V) \equiv (B-V) - (B-V)_0,$$

$$E(U-B) \equiv (U-B) - (U-B)_0$$

(subscript zero denotes intrinsic values).

$$A_V/E(B-V) = 3.2 \pm 0.2 \quad \text{(normal regions)}$$

$$\frac{E(U-B)}{E(B-V)} = 0.72 + 0.05E(B-V).$$

Relationship of reddening $E(B-V)$ to the hydrogen column density:

$$\langle N(\mathrm{HI} + H_2)/E(B-V) \rangle = 5.8 \times 10^{21} \quad \text{atoms cm}^{-2}\,\text{mag}^{-1},$$

$$\langle N(\mathrm{HI})/E(B-V) \rangle = 4.8 \times 10^{21} \quad \text{atoms cm}^{-2}\,\text{mag}^{-1}$$

(Bohlin *et al.*, *Ap. J.*, **224**, 132, 1978).

Visual extinction to the galactic center:

$$A_V \approx 30 \quad \text{mag}$$

(Becklin *et al.*, *Ap. J.*, **151**, 145, 1968).

The mean color excess $\bar{E}_{B-V}(b)$ at galactic latitude b for objects outside the absorbing layer can be estimated by:

$$\bar{E}_{B-V}(b) = 0.06 \operatorname{cosec}|b| - 0.06$$

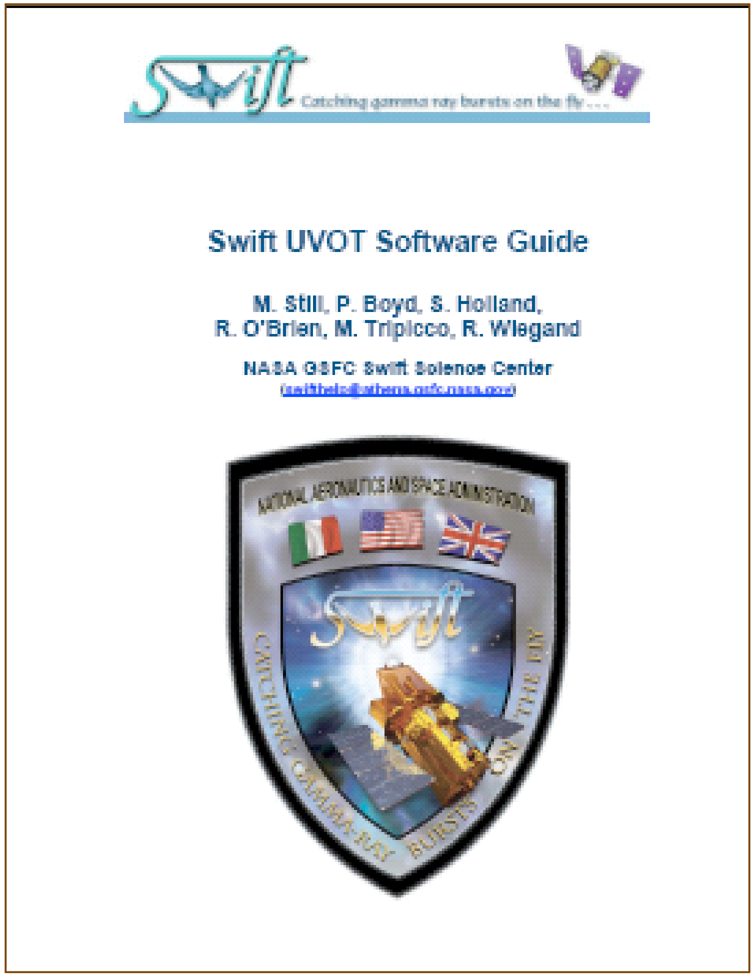
(Woltjer, L., *Astron. Astrophys.*, **42**, 109, 1975).

A more general expression giving an estimate of interstellar absorption can be found in de Vaucouleurs *et al.*, *Second Reference Catalogue of Bright Galaxies*, University of Texas Press, 1976.

$$m_i = m_i^0 + A(\lambda_i)$$

UVOT data analysis: References

http://swift.gsfc.nasa.gov/docs/swift/analysis/


Swift UVOT Software Guide

M. Still, P. Boyd, S. Holland,
R. O'Brien, M. Tripicco, R. Wiegand

NASA GSFC Swift Science Center

uvotcaldb_darkframe_02.pdf

uvot_caldb_filtertransmission_02.pdf

uvot_caldb_psf_01a.pdf

uvot_caldb_zeropoints_01a.pdf

uvot_caldb_counttofluxratio_01a.pdf

uvot_caldb_v1_2.pdf

UVOT Digets

CALDB files

- Latest CALDB →2006-02-14
- BAT (20051103),
- XRT (20060104),
- UVOT(20051118)
- MIS(20060214)
- An updated version of the caldb.config file is available at ftp://heasarc.gsfc.nasa.gov/caldb/software/tools .

UVOT FTOOLS

fhelp uvot

* uvot2pha - Create a pha file from a UVOT image and region files.
* uvotbadpix - Create pixel quality map from a bad pixel list.
* **uvotchain - Swift UVOT event list processing script.
* uvotdetect - Detect sources in an UVOT image using XIMAGE.
* uvotevgrism - Filter a UVOT grism event list and determine wavelength
* uvotexpmap - Generate exposure maps for UVOT sky images.
* uvotflatfield - Perform flatfield correction for UVOT images.
* uvotimgrism - Extract UVOT grism spectra and calculate wavelength scale.
* uvotimsum - Sum UVOT sky images or exposure maps.
* uvotmag - Photometrically calibrate sources in a UVOT image.
* uvotmaghist - Generate magnitude history for UVOT image file.
* uvotmodmap - Correct a UVOT image for modulo-8 spatial fixed-pattern noise.
* uvotpict - Creat a finding chart image.
* uvotproduct - Create level III science products from Level II UVOT data.
* uvotrmfgen - Create a UVOT response matrix.
* uvotscreen - Filter a UVOT event list.
* uvotsequence - List and visualize UVOT observing sequences.
* uvotskycorr - Attempt to aspect correct UVOT sky images.
* uvotsource - Instrumental source magnitude derived from image.
* uvotttfc - UVOT TDRSS finding chart processing.

Zeropoints

- ZPTU = 18.38 Zero point of U
- ZPTB = 19.16 Zero point of B
- ZPTV = 17.88 Zero point of V
- ZPTUVW1 = 17.69 Zero point of UVW1
- ZPTUVW2 = 17.77 Zero point of UVW2
- ZPTUVM2 = 17.29 Zero point of UVM2
- ZPTWHITE= 19.78 Zero point of WHITE

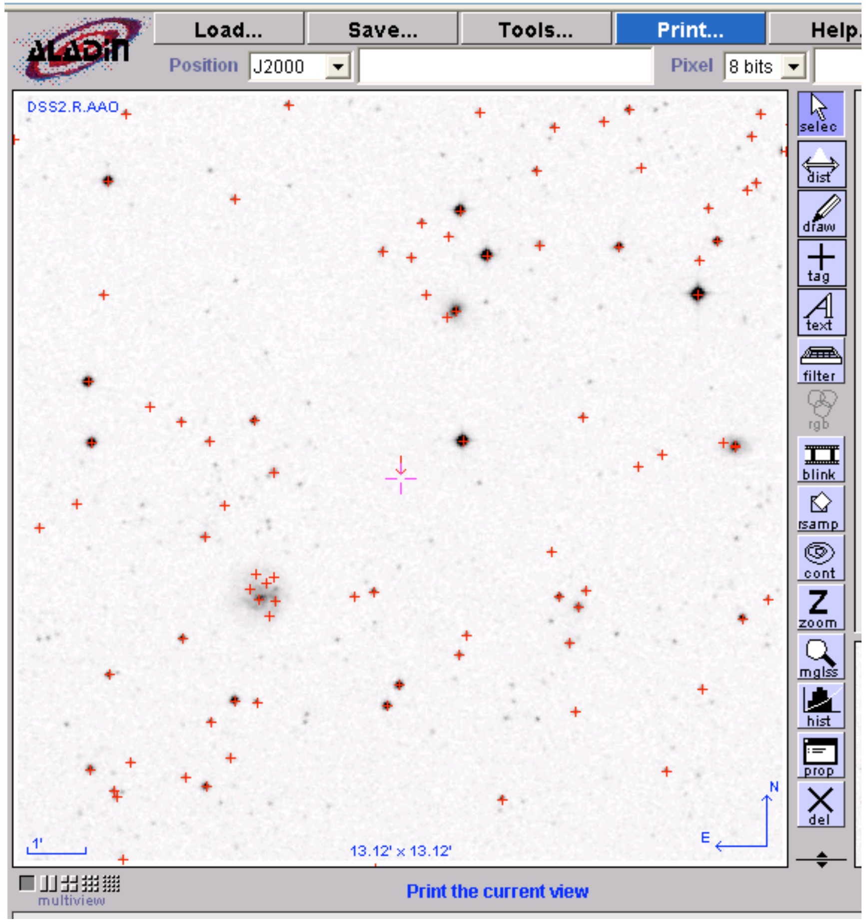
m = ZPT - 2.5 * log10(C)

Step 0 - Finding Charts

GRB050603

RA: 02 39 53.38

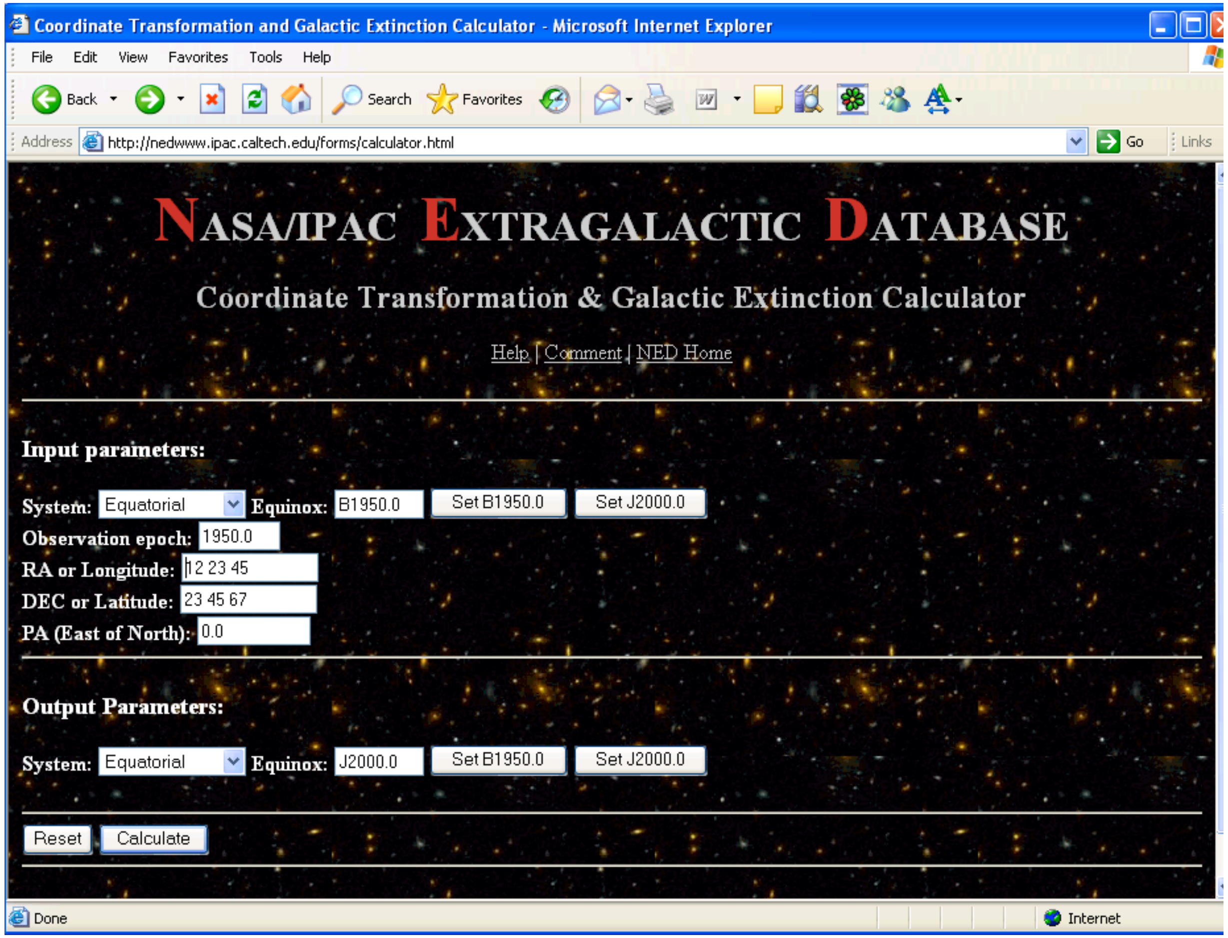
DEC: -25 11 24.1



- http://skyview.gsfc.nasa.gov/cgi-bin/titlepage.pl
- http://skyview.gsfc.nasa.gov/cgi-bin/skyviewjadv.pl
- http://www.ledas.ac.uk/DSSimage

Extinction Calculator

http://nedwww.ipac.caltech.edu/



E(B-V) = 0.020 mag.

Bandpass (microns)	A_lambda (mag)
U (0.34)	0.110
B (0.44)	0.087
V (0.54)	0.067
R (0.65)	0.054
I (0.80)	0.039
J (1.27)	0.018
H (1.67)	0.012
K (2.22)	0.007
L'(3.81)	0.003

Schlegel et al (ApJ 500, 525, 1998)

UV - Extinction

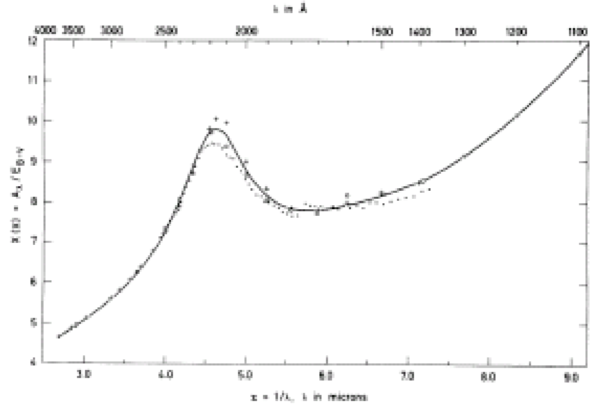


Figure 1. The UV extinction $X(x) = A_\lambda / E_{B-V}$ against $x = 1/\lambda$ with λ in microns. + *OAO-2* data of C76 (Code *et al.* 1976); · *TD-1* data of N75 (Nandy *et al.* 1975); ○ *TD-1* data of N76 (Nandy *et al.* 1976). The full line curve is from the fits of Table 2.

Step 1 – Download the data

http://heasarc.gsfc.nasa.gov/cgi-bin/W3Browse/swift.pl

coordinates, D: get list of data products, X: analyze data products using Hera, B: ADS bibliography holdings,
Scroll down below tables to select Data Products and Further Actions.

Swift Master Catalog (swiftmastr)

Select All	Related Links	Services	name	obsid	ra	dec	start time	processing date	xrt exposure [s]	uvot exposure [s]	bat exposure [s]	arc d
		O R N S D X	GRB050603	00131560002	02 39 48.21	-25 13 08.5	2005-06-03 23:57:31	2005-07-06	87253.14700	64004.29700	82644.14800	2005
		O R N S D X	GRB050603	00131560012	02 39 49.20	-25 13 14.8	2005-06-17 23:30:51	2005-07-07	57648.31900	51154.18000	55581.40900	2005
		O R N S D X	GRB050603	00131560009	02 39 48.86	-25 13 05.6	2005-06-14 23:32:54	2005-07-05	20242.20100	13713.10100	19448.18300	2005
		O R N S D X	GRB050603	00131560011	02 39 49.13	-25 13 21.1	2005-06-16 23:34:00	2005-07-05	18765.63400	15791.77800	18641.29900	2005
		O R N S D X	GRB050603	00131560003	02 39 48.85	-25 13 11.6	2005-06-06 23:33:32	2005-07-07	17488.27500	10622.06200	16798.65000	2005
		O R N S D X	GRB050603	00131560004	02 39 48.98	-25 13 02.4	2005-06-07 23:44:36	2005-07-06	15079.05900	12450.09600	14076.02900	2005
		O R N S D X	GRB050603	00131560010	02 39 48.30	-25 13 30.5	2005-06-15 23:45:54	2005-07-05	14912.39700	14198.32900	14530.25600	2005
		O R N S D X	GRB050603	00131560006	02 39 49.32	-25 13 11.7	2005-06-09 23:38:52	2005-07-05	14482.20400	13411.48500	13729.07500	2005
		O R N S D X	GRB050603	00131560005	02 39 49.19	-25 13 15.9	2005-06-08 23:41:21	2005-07-06	12323.10400	13045.76500	13404.11700	2005
✓		O R N S D X	GRB050603	00131560007	02 39 53.38	-25 11 24.1	2005-06-10 23:44:40	2005-07-06	9100.69300	8510.34200	8757.00000	2005
	TDRSS	O R N S D X	GRB050603	00131560001	02 39 47.32	-25 12 27.7	2005-06-03 15:39:43	2005-06-11	8988.93200	8965.59300	9284.28000	2005
		O R N S D X	GRB050603	00131560008	02 39 48.48	-25 13 24.8	2005-06-14 19:01:13	2005-07-05	4662.22400	0.00000	4379.06000	2005
		O R N S D X	GRB050603	00131560013	02 39 49.06	-25 13 08.9	2005-06-23 21:37:29	2005-07-05	4033.91000	3643.41300	3802.05700	2005
	TDRSS	O R N S D X	GRB050603	00131560000	00 28 52.31	-59 58 10.0	2005-06-03 06:14:04	2005-06-11	0.00000	0.00000	4224.51700	2005

14 rows retrieved from swiftmastr

Are you interested in data products?	**Further Actions:**

wget --passive-ftp -q -nH --cut-dirs=5 -r -l0 -c -N -np --retr-symlinks ftp:
egacy.gsfc.nasa.gov/FTP/swift/data/obs/2005_06//00131560007/uvot/image/sw00
1310007uvv_sk.img.gz

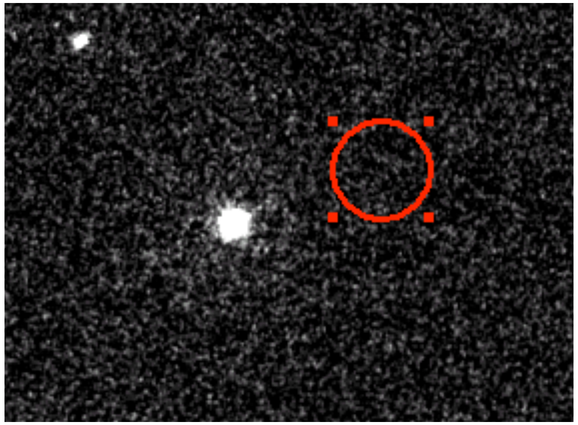
Step 3 – Inspect your data

- Open DS9
  - File ->Open deridered file
  - Scale -> 99-90%

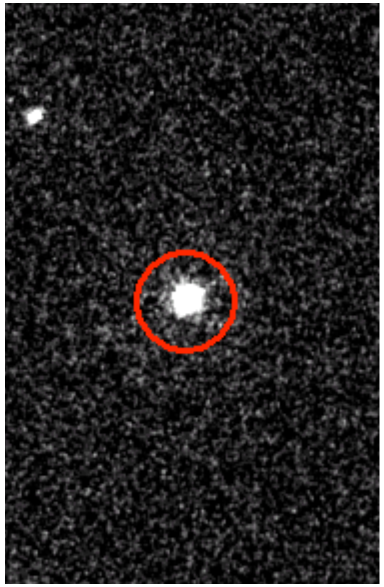
- ftlist filename K include='EXTN*,OBJECT,FILTER,DATE-*,EXPO*,EXP*'

Step 4 – Create regions files

- Open DS9
  - File ->Open deridered file
  - Scale -> 99-90%
  - Find the object using the Finding chart & Coord
  - Region ->File coordinate System ->WCS
    - Select region



BKG



SRC

Step 4 – Run uvotsource

gino@tosti-nb ~...uvot/image]$ plist uvotsource

```
[gino@tosti-nb ~...uvot/image]$ uvotsource img_V.fits
Source region file [src.reg] :
Background region file [bkg.reg] :
Filter <U|B|V|UVW2|UVM2|UVW1|WHITE|MAGNIFIER|DEFAULT> [V] :
Background threshold <1 - 100> [3] :
Tk startup failed: /xtk device unavailable
        Position: RA = 2h 39m 51.88s, Dec = -25h 10m 8.5s (J2000)
          Source: V = 13.17 +/- 0.03 (59.6-sigma)
      Background: V = 22.13 arcsec^-2
 Background-limit: V = 18.00 (3-sigma)
Coincidence-limit: V = 12.99
```

Apply extrintion correction & flux trsnsformation

DATE	UT	Fil	Mag	Mder	Merr	flux	Fluxerr
2005-07-26	02:12:53	UVW2	17.26	14.53	0.23	1.4833e-26	3.1388e-27
2005-07-26	05:25:53	UVW2	17.28	14.55	0.22	1.4563e-26	2.9475e-27
2005-07-26	08:38:52	UVW2	16.88	14.15	0.18	2.1049e-26	3.4858e-27
2005-07-26	10:14:53	UVW2	17.76	15.03	0.32	9.3593e-27	2.7554e-27
2005-07-26	13:27:52	UVW2	17.58	14.85	0.25	1.1047e-26	2.5408e-27
2005-07-26	16:40:53	UVW2	17.33	14.60	0.23	1.3907e-26	2.9428e-27
2005-07-26	19:53:53	UVW2	17.73	15.00	0.32	9.6215e-27	2.8326e-27
2005-07-26	21:29:53	UVW2	17.06	14.33	0.20	1.7834e-26	3.2814e-27

Link

- http://heasarc.nasa.gov/docs/heasarc/caldb/swift/
- http://swift.gsfc.nasa.gov/docs/swift/analysis/
- http://heasarc.nasa.gov/docs/swift/about_swift/uvot_desc.html
- http://heasarc.nasa.gov/docs/heasarc/caldb/swift/docs/uvot/uvot_caldb_v1_3.pdf
- http://heasarc.nasa.gov/docs/swift/analysis/uvot_digest.html#analysis
- http://heasarc.nasa.gov/docs/swift/results/refereed/ref_2005.html