Photometric Techniques I
Preliminary reductions and calibrations

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.

CCD “optical” PHOTOMETRY

vs.

Phtoelectric photometry

IR array photometry

STELLAR PHOTOMETRY

SURPHACE PHOTOMETRY

STELLAR CCD PHOTOMETRY

Targets: star clusters, field stars in the MW and in external galaxies. Peculiar isolated stars (SNs, Nova stars, NS, GRBs, X-Ray sources…). Variable stars (stars with planets). Typical goal 1-5% accuracy in the standard U, B, V, R, I (Gunn z)

Why do we need accurate stellar photometry (1-5%) ?

Example: old star clusters, K giants

ΔV 0.1 mag. at TO~Δage 1.5 Gyr
$\Delta E(B-V)=0.03 \sim \Delta V$ 0.1 mag.

$\Delta(B-V)=0.03 \sim \Delta T=100K$ ➡
➡ $\Delta[Fe/H] \sim 0.07$, $\Delta[Ca/Fe] \sim 0.1$!
Absolute calibration required

$$B - V = -0.71 + 7090T^{-1}$$

$$T = 7090/[(B - V) + 0.71] \qquad (\mathrm{K}).$$

$$\downarrow$$

$$B-V = -0.865 + \frac{8540}{T}$$

$$T = 8540/[(B-V)+0.865]$$

$$\sim \Delta T = 35^{o}K \div (B-V) = 0.01$$

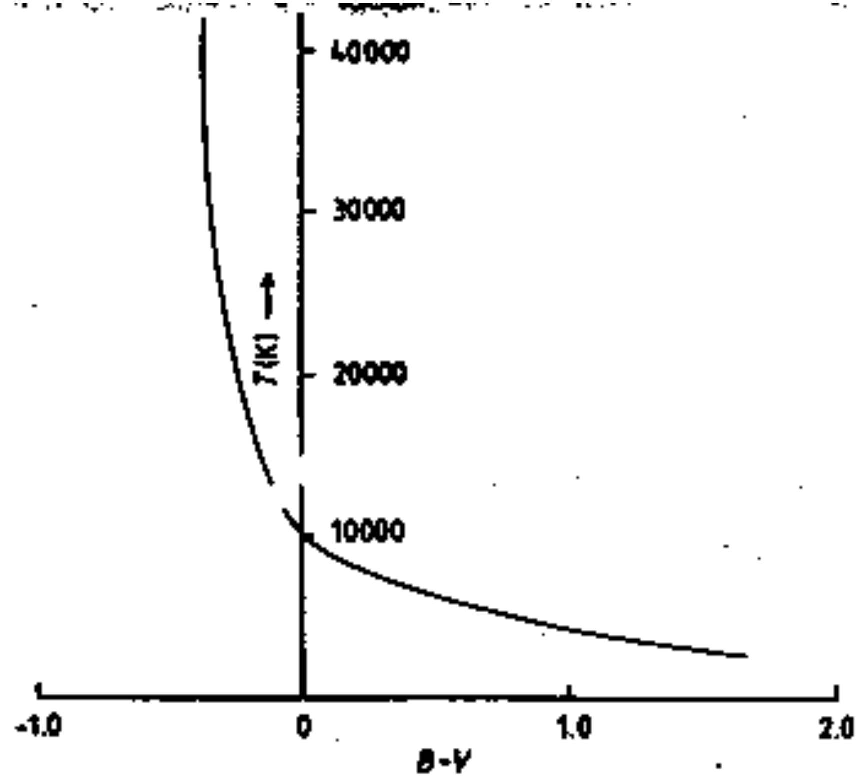
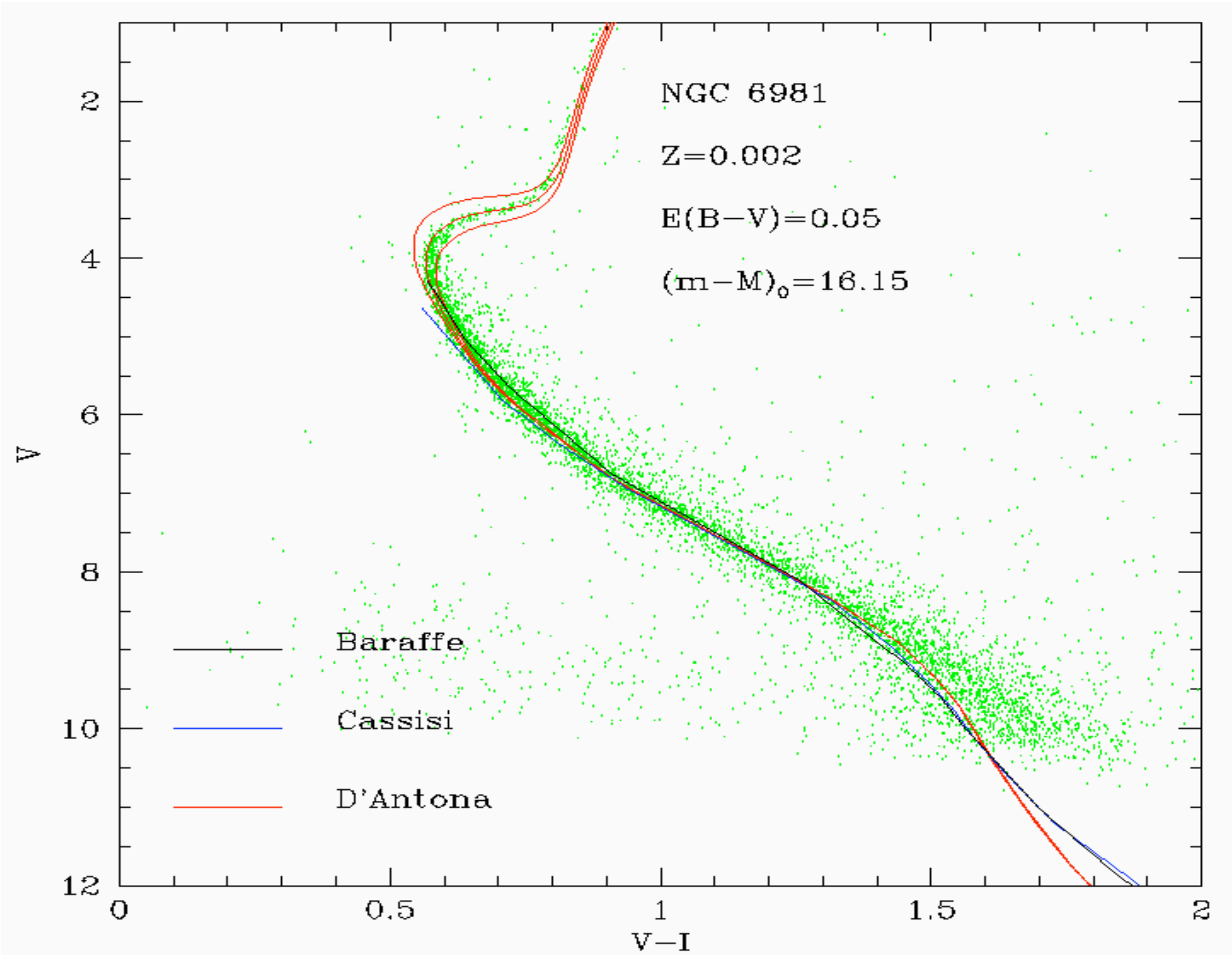


Figure 3.1.8 Observed $B - V/T$ relationship for the whole of the main sequence.

Color-magnitude diagrams:



REFERENCES

CCD photometric properties

- **MACKAY, ARAA, 24, 259, 1986**
- **LEACH et al., PASP, 92, 233, 1980**
- **GUDEHUS et al., AJ, 90, 130, 1985**
- **MELLIER et al., AA, 157, 96, 1986**
- **AMELIO, Scient. American, ?, 1974**

Data calibration

BESSELL, PASP, 89, 591,1979
COUSINS, MNASSA, 39, 93, 1980
BECKERT et al., PASP, 101, 849, 1989
ORTOLANI, CCD ESO Manual:calibration, 1992

Reduction problems, errors observing techniques, sampling

- STETSON, Dom. Astr. Obs. Prepr., 1988 (flats, accuracy)
- STETSON, PASP, 117, 563, 2005 (cal. accuracy)
- PEDERSEN, ESO DANISH Manual, 1984 (obs. techn.)
- ORTOLANI, “The optimization of the use... ESO/OHP workshop, 1986, p. 183
- KING, PASP, 95, 163, 1983 (sampling, size)
- Buonanno et al., PASP, 101, 294, 1989 (sampling)
- DIEGO, PASP, 97, 1209, 1985 (size)
- MATEO, PHD thesis (completeness)

Stellar Photometry Packages

RICHFILD	Tody	1981	KPNO
INVENTORY	West, Kruszewsky	1981	Irish Astr. J. 15, 25 (MIDAS man.)
ROMAFOT	Buonanno et al.	1983	A&A, 126, 278
DAOPHOT	Stetson	1987	PASP, 99, 191
ALLSTAR	Stetson	1994	PASP, 106, 250
ALLFRAME	Stetson	1994	PASP, 106, 250
DoPHOT	Schechter,Mateo Shara	1993	PASP 105, 1342
ePSF	Anderson, King	2000	PASP, 112, 1360

DAOPHOT

Plus a number of less used or generic photometry softwares (Wolf, Lund Starman, SEXTRACTOR, etc.)

Preliminary reductions of CCD images

corr. i. = [(raw-bias)-(dark-bias)]/flat f.

flat field = (sky flat – bias)/ave. value

High and low frquency flat fields may be required from the sky (low fr.) and from the dome (high fr.)

IF:

the detector is linear, the bias is constant and the gain does't depend on the signal. Problem: the nature and color of the flat field. Subtraction or division ? Check the presence of reflected light.

In the infrared (JHK) the sky must be subtracted !

The preliminary reduction is a complex operations. It requires an evaluation of the noise propagation for each mathematical operation. For example:

if: $c = a/b$ then $\sigma_c^2 = \sigma_a^2/b^2 + a^2/b^4\sigma_b^2$

If a and b are independent.

In many cases the bias and dark subtraction can be replaced by a fixed value.

BIAS

1) from overscan columns (problems with charge transfer)

2) from very short dark exposures (CCD “heating” probelms)

3) from signal vs. noise diagrams (from flat field couples)

Errors in the bias level affect the photometric accuracy

FLAT FIELDS

1) from dome exposures
2) from twilight sky
3) from internal lamps

Problems with: REFLECTED LIGHT (sky concentration), light distribution, colors, signal to noise ratio. Errors up to 10%.

Combined flat field corrections sometimes needed
Check the noise of the corrected images
Check the accuracy with standard stars

Effect of the flat field corrections on the noise of a image.

The noise decreases with the scale length because of the bigger sampling.

From Leach et al. 1980.

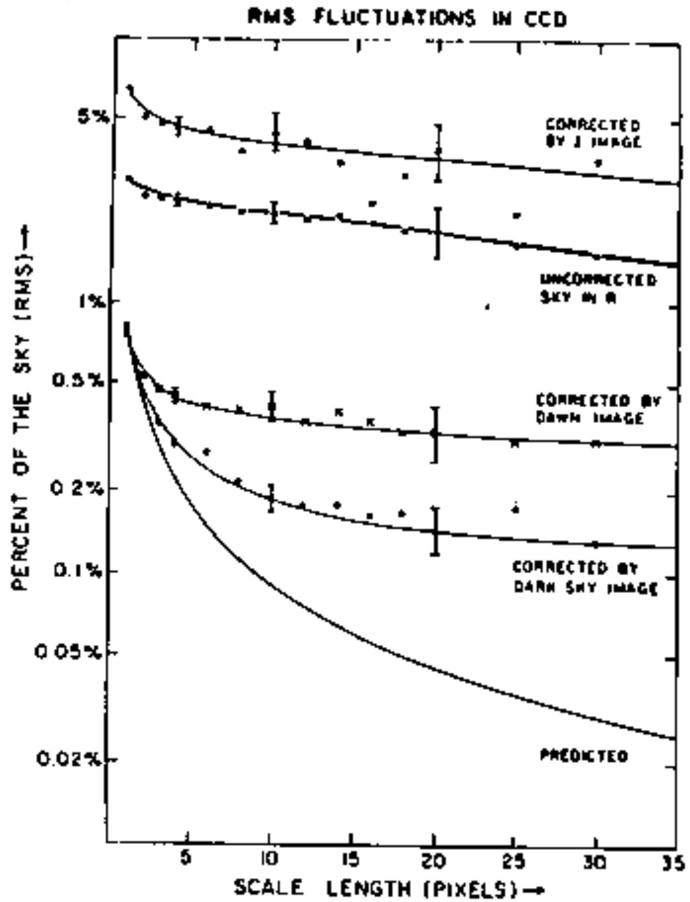


FIG. 6—The rms variation between the means of groups of pixels as a function of the scale length for four images of the night sky. The top plot is for image (d) of Table I, running through image (g) at the bottom. The plots exhibit a progression of increasingly accurate flat-field correction, with the best results obtained when sky was used to correct sky and the worst results occurring when a flat-field of the wrong color was used. The predicted line assumes that counting and readout noise are the only contributors to the nonuniformities, and varies as the inverse of the scale length.

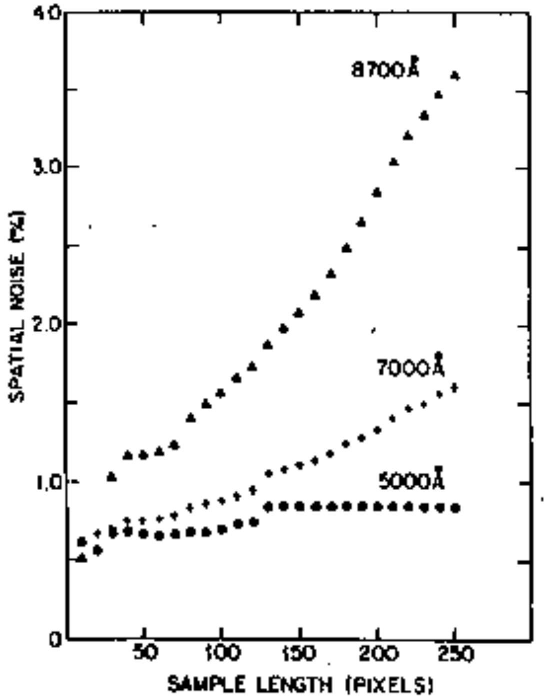
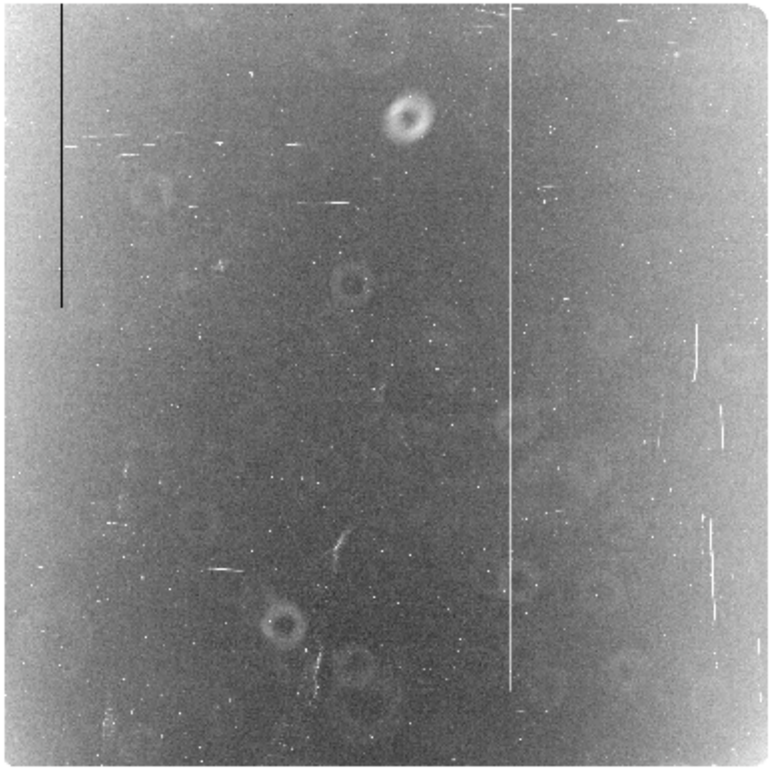


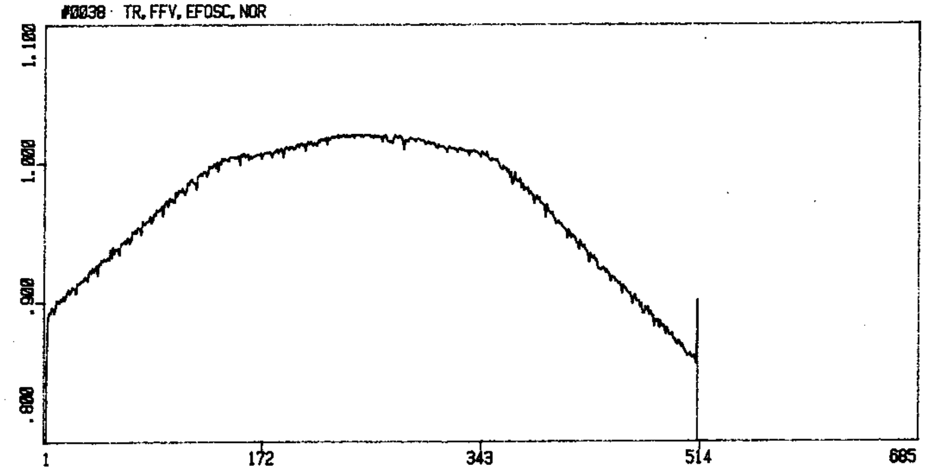
FIG. 11. CCD spatial noise as a function of wavelength and sample size.

Mo, 28 Aug 2006 18:42:05 MIDAS version: 99NOV



14 2024

Frame : ffb
Identifier : FFB,sky,av6,norm
ITT-table : ramp.itt
Coordinates : 14, 6 : 2024, 2016
Pixels : 1, 1 : 512, 512
Cut values : 0.9, 1.1
User : ortolani



Vignetted flat field

CCD #3

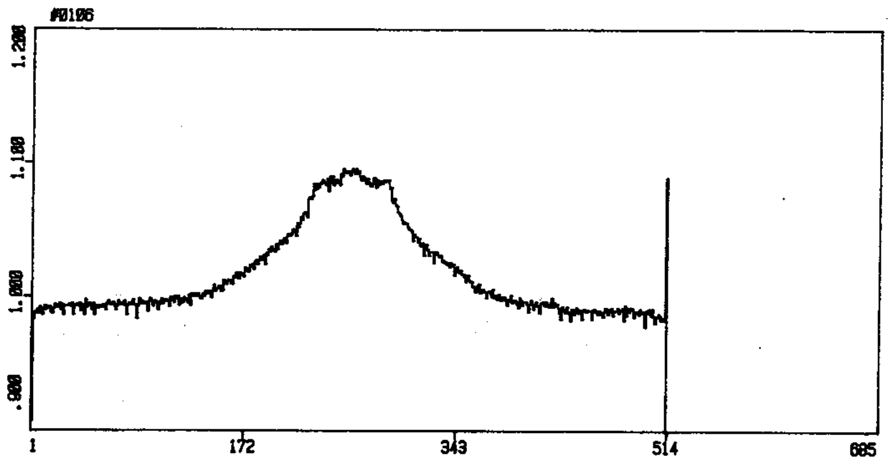
Vs.

sky concentration

CCD #11

(EFOSC)

FF V AVS 8180 EFOSC + CCD#11
XADD 160,165
SCAN Y



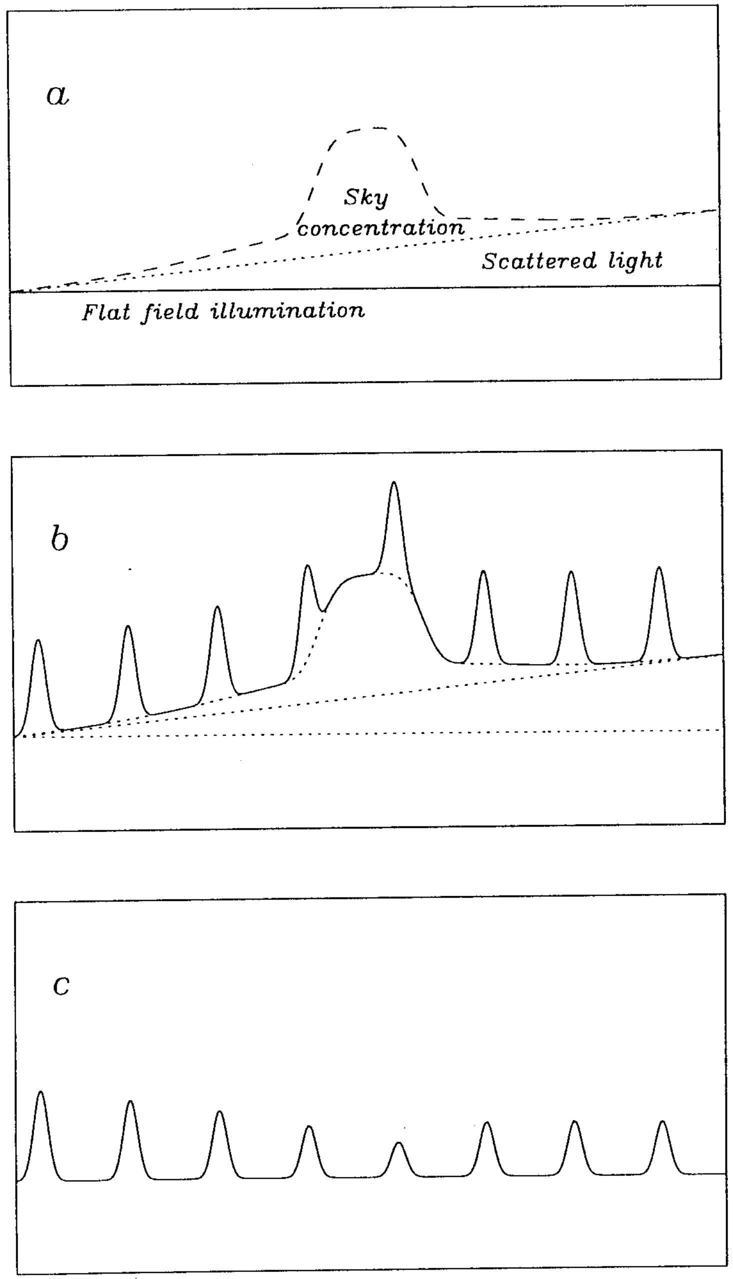


Figure 1: *a)* An example of a flatfield exposure from a focal reducer type instrument with the various error contributions shown as dashed and dotted lines.

b) An example of a science exposure with eight equal brightness stars superimposed on a flat sky background. The scattered light and sky concentration is assumed to originate preferentially from the sky light and thus to be identical to the distribution in the flat field in panel a.

c) The resulting science frame after flatfielding with the uncorrected flatfield from panel a. Note that the background appear perfectly flat but the stars no longer have equal brightness. These intensity errors are the ones we try to determine and correct for.

Photometric calibration, standard stars out of the field

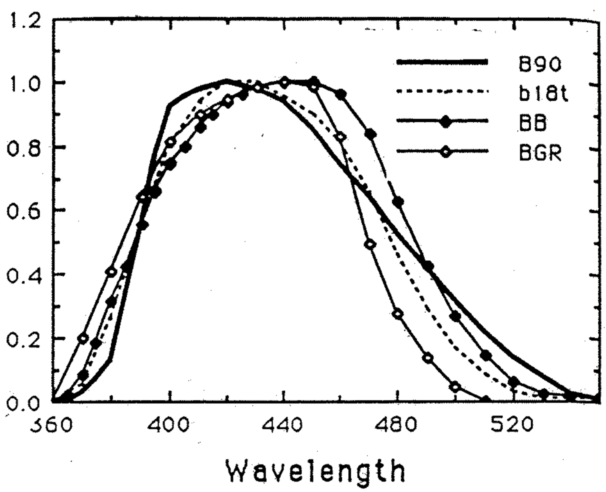
Problems: different photometric systems, red leaks, seeing variations, air mass corrections, shutter timing, aperture corrections, sky transmission variations (also sky brightness fluctuations in the IR).
Calibration errors +/-0.01 - 0.02 mag.

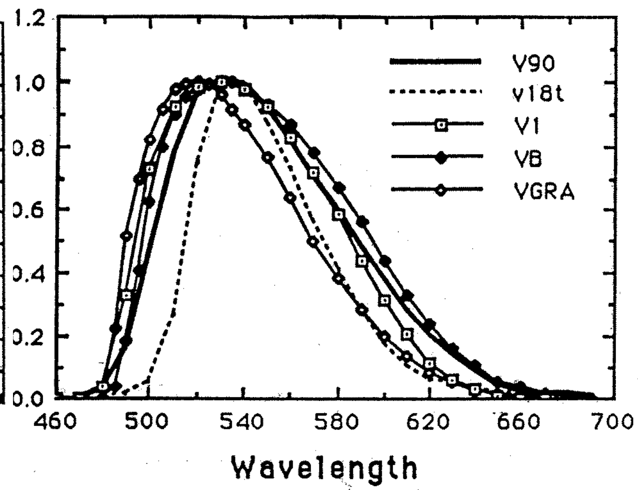
It is important to realize that, even if the filters are properly selected any observational system is always different from the standard one. Indeed, the collected flux depends on at least 6 different terms:

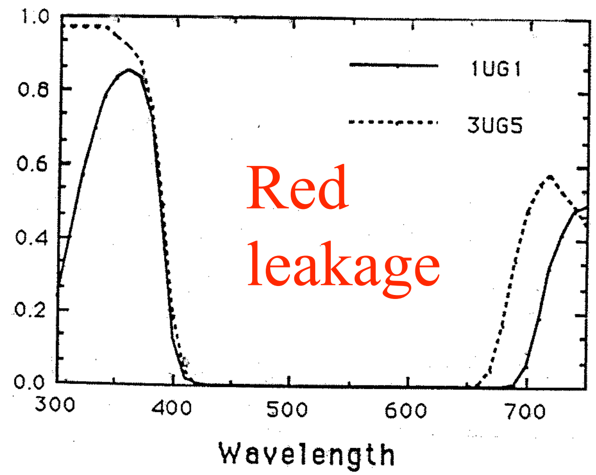
$$\text{Signal}=F(\lambda)(1-\varepsilon)R(\lambda)A(\lambda)K(\lambda)Q(\lambda)$$

$F(\lambda)$ incoming flux
ε fraction of the obscured mirror
$R(\lambda)$ mirror reflectivity
$A(\lambda)$ atmospheric absorption
$K(\lambda)$ filter trasmission curve
$Q(\lambda)$ detector quantum efficency

In the case of CCD photometry the different $Q(\lambda)$ is responsible for significative differences, including red leaks.







Q(λ) for different CCDs

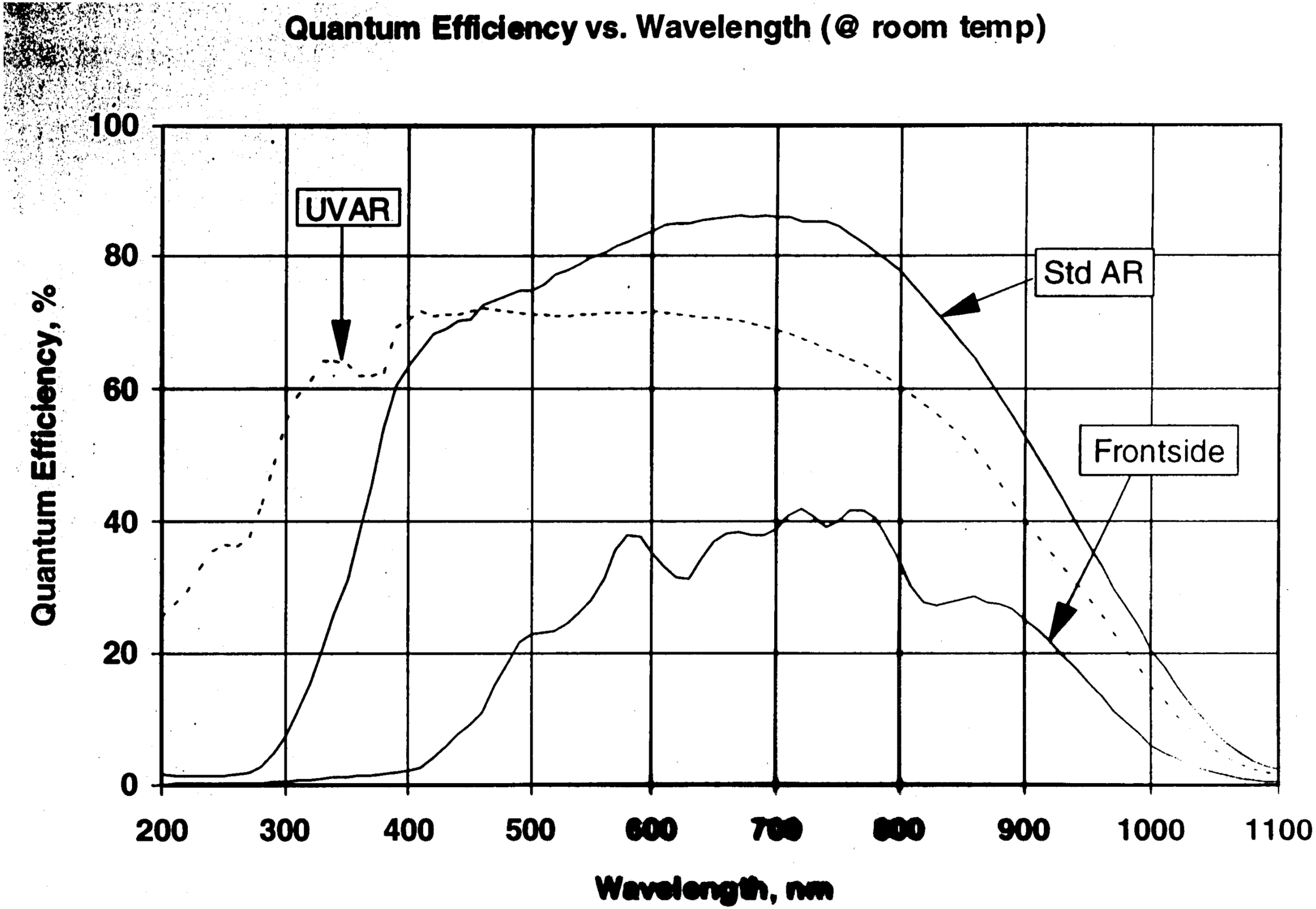
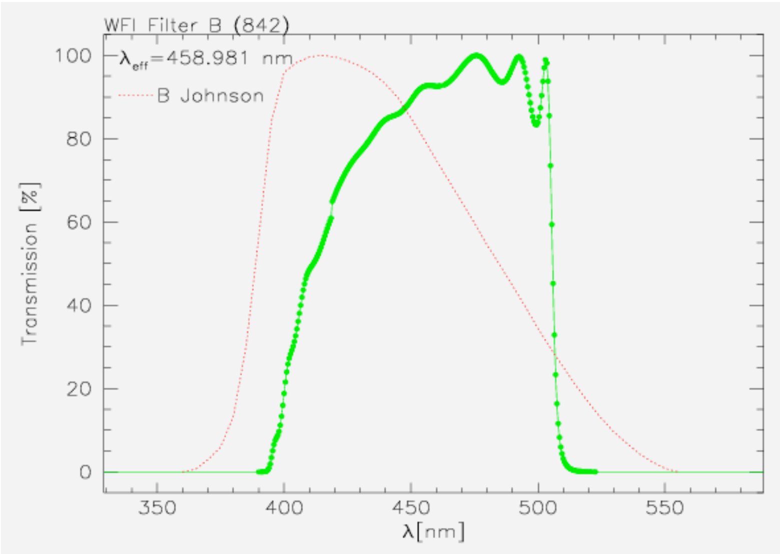
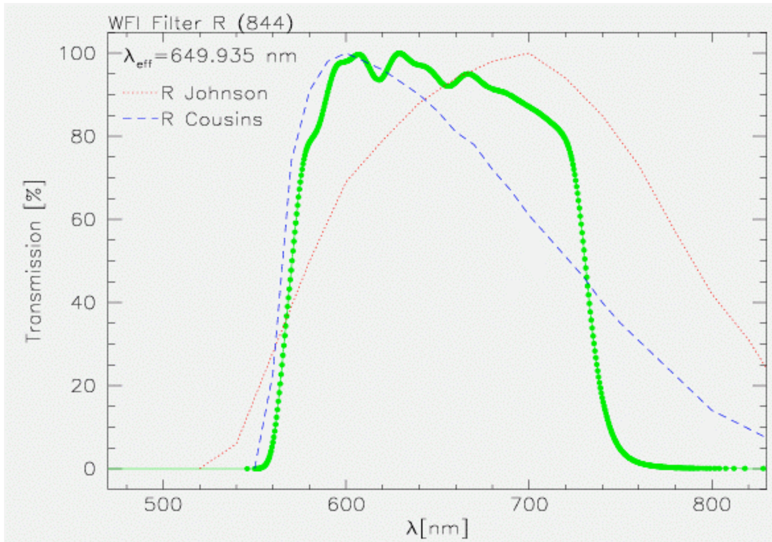
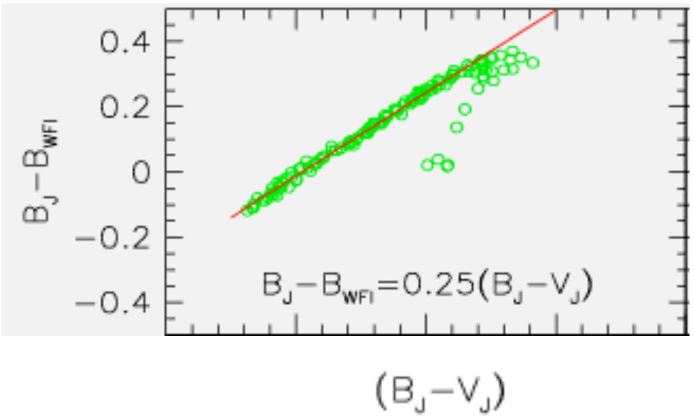


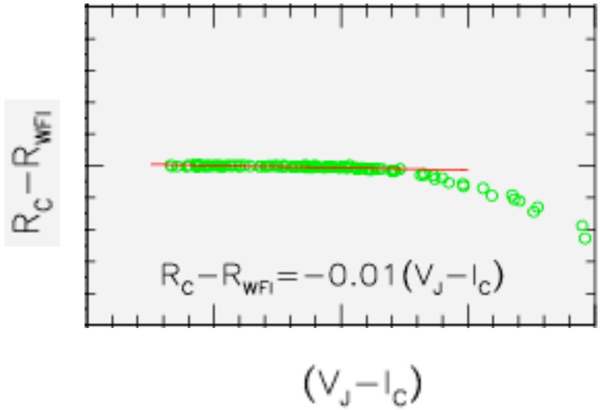
FIGURE 7 *Typical QE curves*

The Asiago Data Base on Photometric Systems lists 218 systems (see http://ulisse.pd.astro.it/ADPS/enter2.html)!!!
But, even when you have chosen your photometric system, you might still be in trouble!









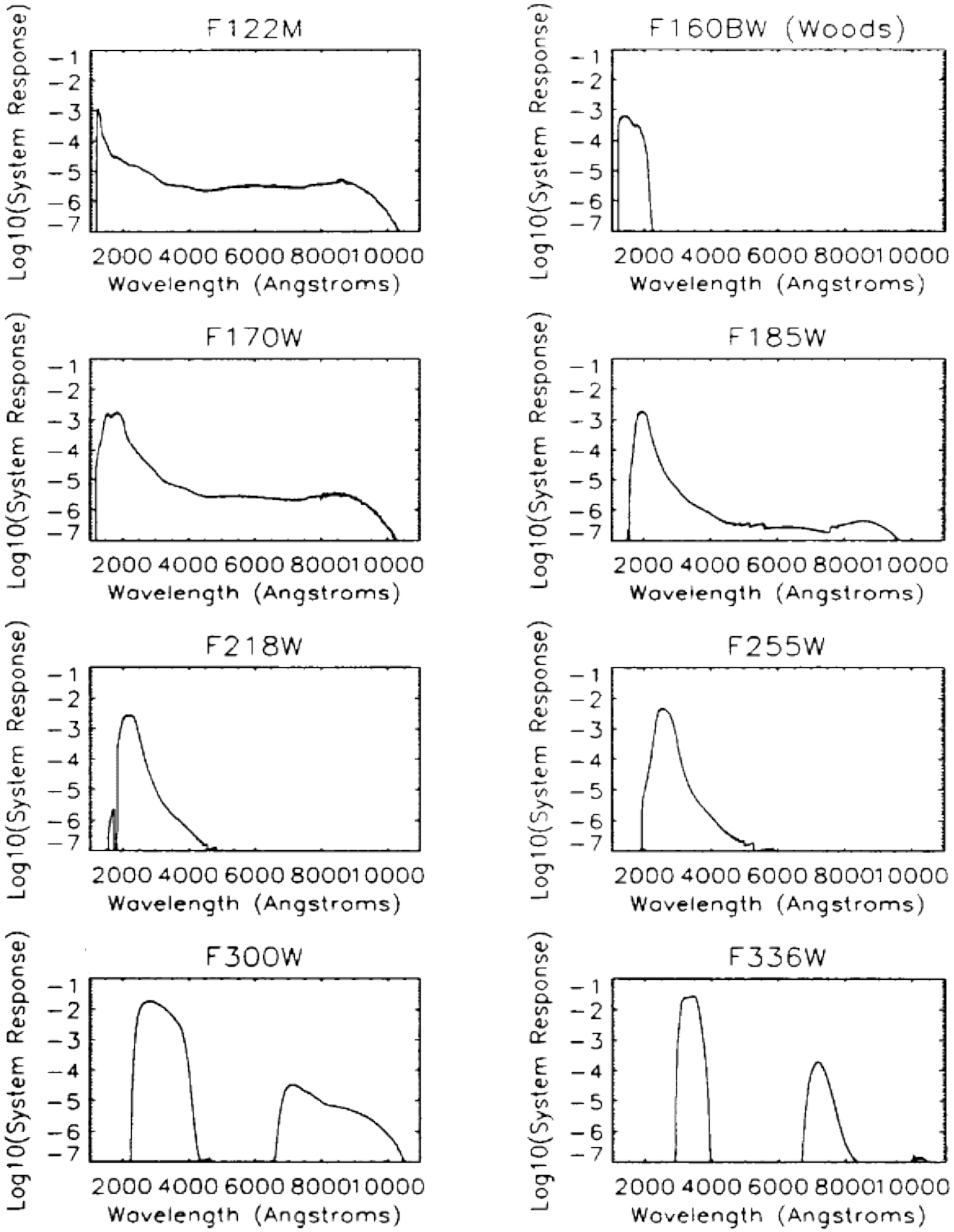
RED LEAKS

Red leaks in the photometric SYSTEMS can be detected cheking the flat fields or the distribution of standard stars measurements.

Simple quantitative considerations show that the red leak tolerance for 1 % absolute photometry should be reduced down to 10^{-5} for the U band 10^{-4} for the B band and 10^{-3} for the V, assuming that it is dominating at 0.9 μ in a 0.1 μ wide band (Ortolani, ESO La Silla techn. note, 1985).

CHECKING THE REAL EXPOSURE TIME

Shutter timing delays may occur. Safe exposure times are around 10 to 30 s.


F122M
F160BW (Woods)
F170W
F185W
F218W
F255W
F300W
F336W
Log10(System Response)
−1
−2
−3
−4
−5
−6
−7
2000 4000 6000 8000 10000
Wavelength (Angstroms)

Photometric calibration of groundbased observations

Let's suppose that we have collected a set of images of our program objects through a set of filters properly designed to reproduce a **"standard" photometric system** for which **a large set of standard stars**, well distributed in the sky, and which span a large color interval are available in the literature.

The standard stars define our photometric system.

In order to calibrate the magnitudes and colors of our program objects, we need to observe also the standard star fields, at different times during the night, making sure that the observed standards cover a sufficently large color interval.

A diagram with the color index vs. the difference between the instrumentalmagnitudes (m=-2.5logI) and the standard ones (from the catalogues will be produced. The linear interpolation to the data will give the slope and the zero point of the calibration equation. Sometimes more complicate interpolations would be needed.

The zero point corresponds to the counts from a m=0 star.

Just an example (for the Johnson-Cousins system):

UBVRI PHOTOMETRIC STANDARD STARS IN THE MAGNITUDE RANGE $11.5 < V < 16.0$ AROUND THE CELESTIAL EQUATOR[1]

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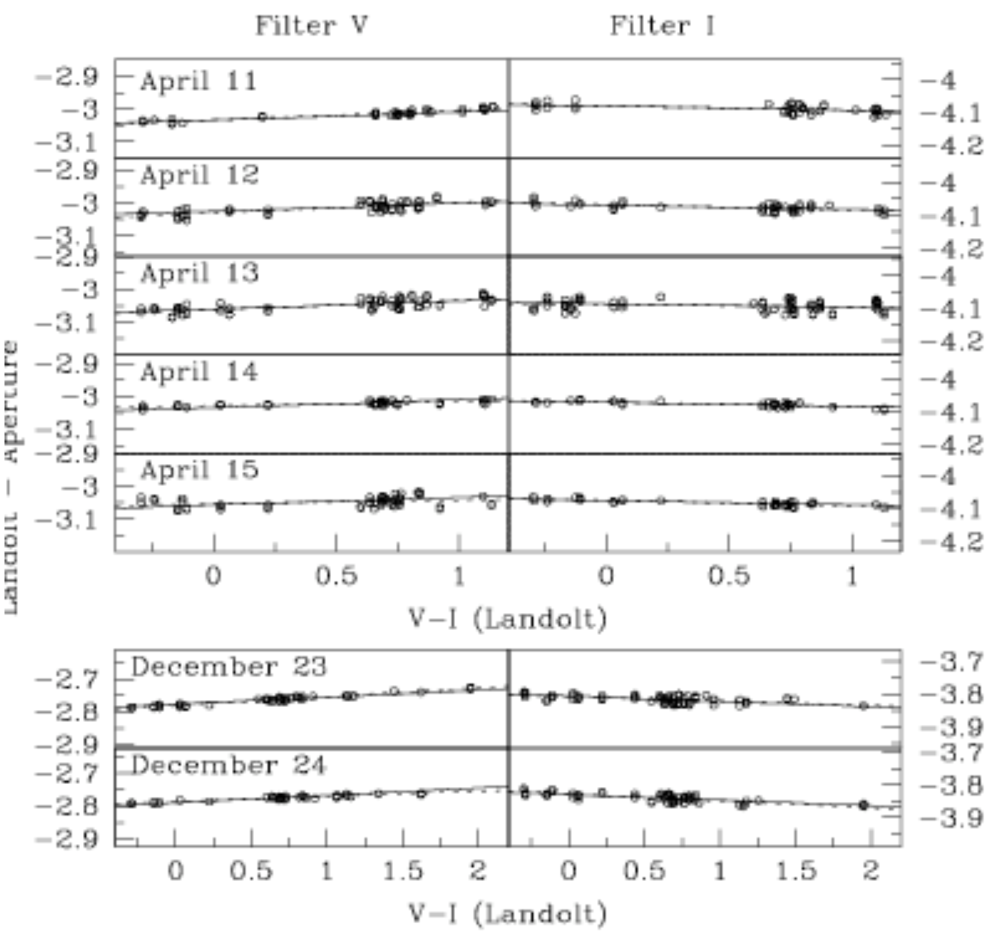
ABSTRACT

UBVRI photoelectric observations have been made on the Johnson–Kron–Cousins photometric system of 526 stars centered on the celestial equator. The program stars within a 298 number subset have sufficient measures so that they are capable of providing, for telescopes of intermediate and large size in both hemispheres, an internally consistent homogeneous broadband standard photometric system around the sky. The stars average 29 measures each on 19 nights. The majority of the stars in this paper fall in the magnitude range $11.5 < V < 16.0$, and in the color range $-0.3 < (B-V) < +2.3$.

Landolt, 1983, AJ, 88, 439
Landolt, 1992, AJ, 104, 340

Photometric information on the standard stars in the Landolt (1992) catalog

											Mean Errors of the Mean						
Star	α(2000)	δ(2000)	V	B-V	U-B	V-R	R-I	V-I	n	m	V	B-V	U-B	V-R	R-I	V-I	Notes
TPHE A	00:30:09	-46 31 22	14.651	0.793	0.380	0.435	0.405	0.841	29	12	0.0028	0.0046	0.0071	0.0019	0.0035	0.0032	
TPHE B	00:30:16	-46 27 55	12.334	0.405	0.156	0.262	0.271	0.535	29	17	0.0115	0.0026	0.0039	0.0020	0.0019	0.0035	1
TPHE C	00:30:17	-46 32 34	14.376	-0.298	-1.217	-0.148	-0.211	-0.360	39	23	0.0022	0.0024	0.0043	0.0038	0.0133	0.0149	
TPHE D	00:30:18	-46 31 11	13.118	1.551	1.871	0.849	0.810	1.663	37	23	0.0033	0.0030	0.0118	0.0015	0.0023	0.0030	
TPHE E	00:30:19	-46 24 36	11.630	0.443	-0.103	0.276	0.283	0.564	34	8	0.0017	0.0012	0.0024	0.0007	0.0015	0.0019	
TPHE F	00:30:50	-46 33 33	12.474	0.855	0.532	0.492	0.435	0.926	5	3	0.0004	0.0058	0.0161	0.0004	0.0040	0.0036	
TPHE G	00:31:05	-46 22 43	10.442	1.546	1.915	0.934	1.085	2.025	5	3	0.0004	0.0013	0.0036	0.0004	0.0009	0.0009	
PG0029+024	00:31:50	+02 38 26	15.268	0.362	-0.184	0.251	0.337	0.593	5	2	0.0094	0.0174	0.0112	0.0161	0.0125	0.0067	
PG0039+049	00:42:05	+05 09 44	12.877	-0.019	-0.871	0.067	0.097	0.164	4	3	0.0020	0.0030	0.0055	0.0035	0.0055	0.0045	
92 309	00:53:14	+00 46 02	13.842	0.513	-0.024	0.326	0.325	0.652	2	1	0.0035	0.0057	0.0028	0.0014	0.0035	0.0014	
92 235	00:53:16	+00 36 18	10.595	1.638	1.984	0.894	0.911	1.806	5	2	0.0058	0.0045	0.0098	0.0031	0.0045	0.0067	
92 322	00:53:47	+00 47 33	12.676	0.528	-0.002	0.302	0.305	0.608	2	1	0.0007	0.0049	0.0028	0.0014	0.0007	0.0007	
92 245	00:54:16	+00 39 51	13.818	1.418	1.189	0.929	0.907	1.836	21	8	0.0028	0.0079	0.0301	0.0024	0.0024	0.0028	
92 248	00:54:31	+00 40 15	15.346	1.128	1.289	0.690	0.553	1.245	4	2	0.0255	0.0160	0.0955	0.0215	0.0145	0.0175	
92 249	00:54:34	+00 41 05	14.325	0.699	0.240	0.399	0.370	0.770	17	8	0.0049	0.0085	0.0114	0.0046	0.0065	0.0073	
92 250	00:54:37	+00 38 56	13.178	0.814	0.480	0.446	0.394	0.840	20	9	0.0022	0.0034	0.0074	0.0022	0.0022	0.0029	
92 330	00:54:44	+00 43 26	15.073	0.568	-0.115	0.331	0.334	0.666	2	1	0.0141	0.0297	0.0163	0.0304	0.0000	0.0304	
92 252	00:54:48	+00 39 23	14.932	0.517	-0.140	0.326	0.332	0.666	41	18	0.0033	0.0055	0.0082	0.0047	0.0072	0.0068	
92 253	00:54:52	+00 40 20	14.085	1.131	0.955	0.719	0.616	1.337	39	17	0.0032	0.0062	0.0221	0.0027	0.0043	0.0050	
92 335	00:55:00	+00 44 13	12.523	0.672	0.208	0.380	0.338	0.719	2	1	0.0007	0.0028	0.0049	0.0000	0.0014	0.0014	
92 339	00:55:03	+00 44 11	15.579	0.449	-0.177	0.306	0.339	0.645	19	8	0.0087	0.0117	0.0126	0.0117	0.0197	0.0177	2
92 342	00:55:10	+00 43 14	11.613	0.436	-0.042	0.266	0.270	0.538	48	34	0.0013	0.0012	0.0023	0.0013	0.0009	0.0016	
92 188	00:55:10	+00 23 12	14.751	1.050	0.751	0.679	0.573	1.254	14	6	0.0096	0.0187	0.0551	0.0051	0.0043	0.0088	2
92 409	00:55:14	+00 56 07	10.627	1.138	1.136	0.734	0.625	1.361	5	3	0.0031	0.0027	0.0085	0.0022	0.0027	0.0018	
92 410	00:55:15	+01 01 49	14.984	0.398	-0.134	0.239	0.242	0.484	27	13	0.0058	0.0064	0.0083	0.0052	0.0102	0.0117	
92 412	00:55:16	+01 01 53	15.036	0.457	-0.152	0.285	0.304	0.589	27	13	0.0054	0.0077	0.0133	0.0069	0.0094	0.0106	
92 259	00:55:22	+00 40 30	14.997	0.642	0.108	0.370	0.452	0.821	3	1	0.0115	0.0219	0.0214	0.0191	0.0202	0.0150	
92 345	00:55:24	+00 51 07	15.216	0.745	0.121	0.465	0.476	0.941	2	1	0.0007	0.0014	0.0339	0.0057	0.0113	0.0057	
92 347	00:55:26	+00 50 49	15.752	0.543	-0.097	0.339	0.318	0.658	4	2	0.0255	0.0280	0.0355	0.0295	0.0755	0.0985	
92 260	00:55:29	+00 37 07	15.071	1.162	1.115	0.719	0.608	1.328	9	4	0.0090	0.0093	0.0477	0.0070	0.0057	0.0080	



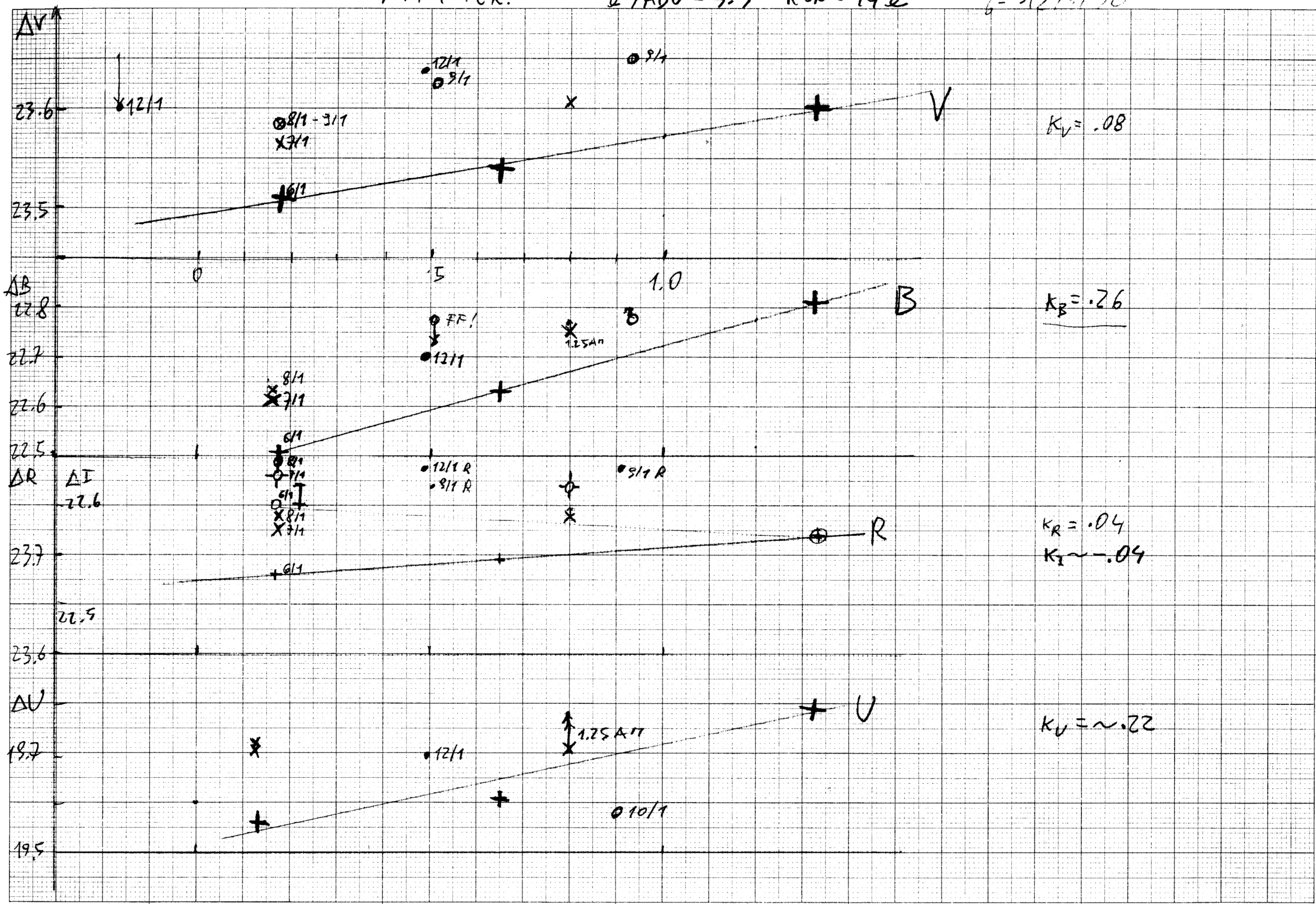
For well designed observing systems, and for not too extreme colors, a linear fit may be enough.

The next step is to calculate the aperture correction, i.e. the zero point difference between the (fitting) instrumental magnitudes of the program stars, and the aperture photometry used to obtain the calibr. coefficents.

Example of calibration eq.s to the Johnson-Cousins standard system for rhe ESO-Dutch telescope (from Rosenberg et al. 2000). Notice the concentration of data around V-I = 0.7. The slope depends mainly on the extreme blue and red standards.

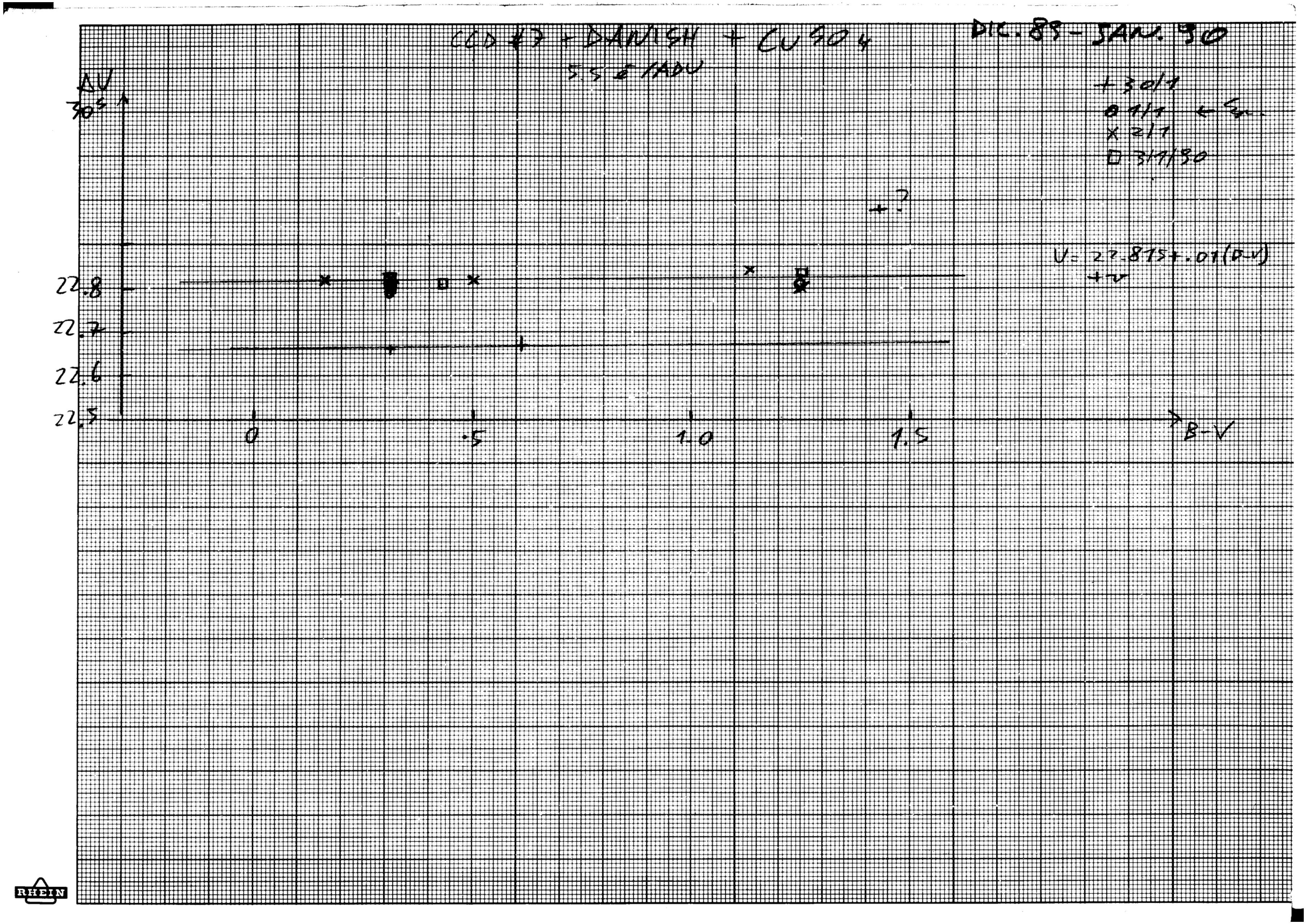
Once the calibration coefficents have been obtained, the corresponding calibration equations can be applied to the instrumental magnitudes of the program stars, to transform them into the calibrated magnitudes.

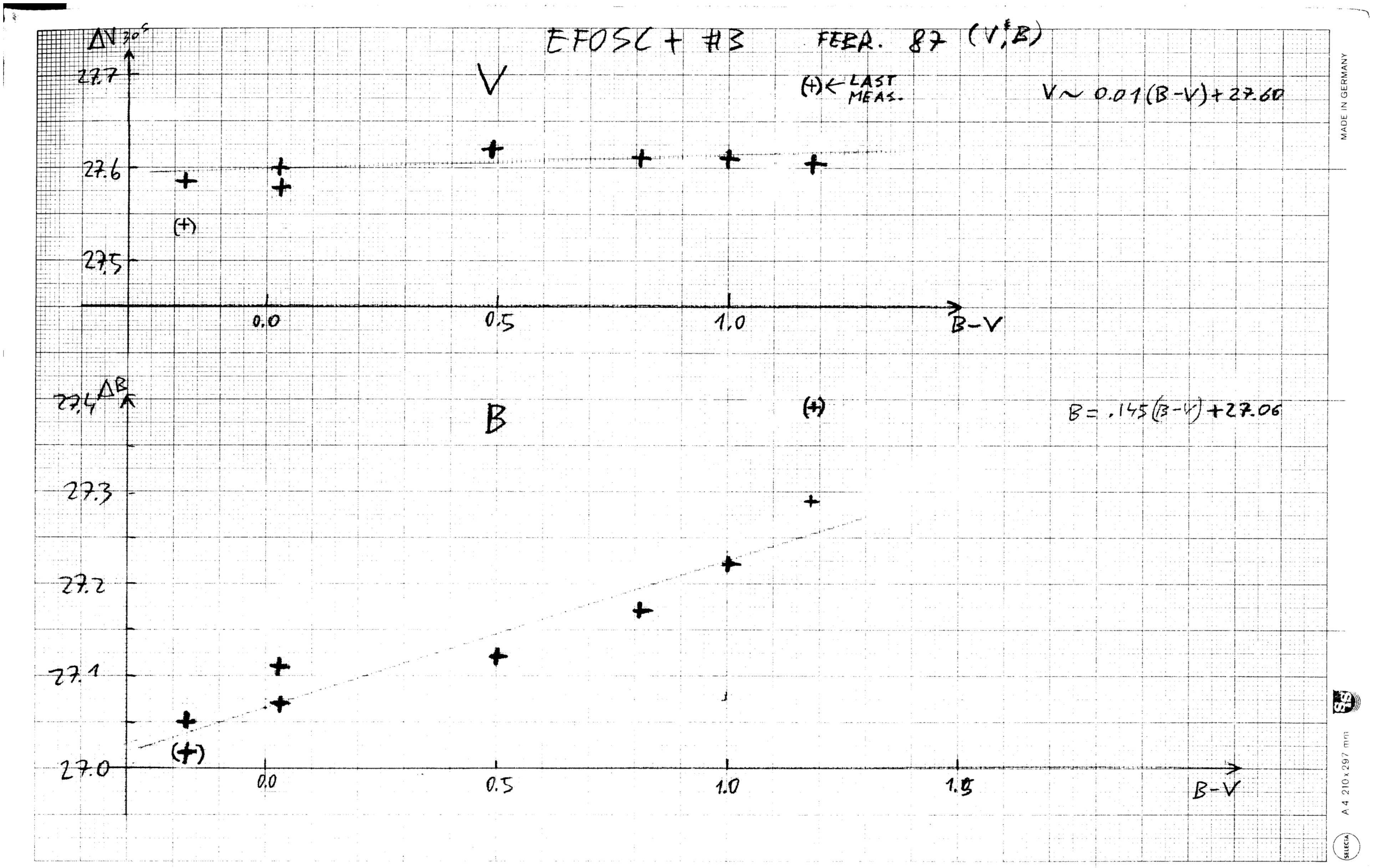
NTT + TEK. e^-/ADU = 5.5   RON = 14 e^- 6-12/1/90

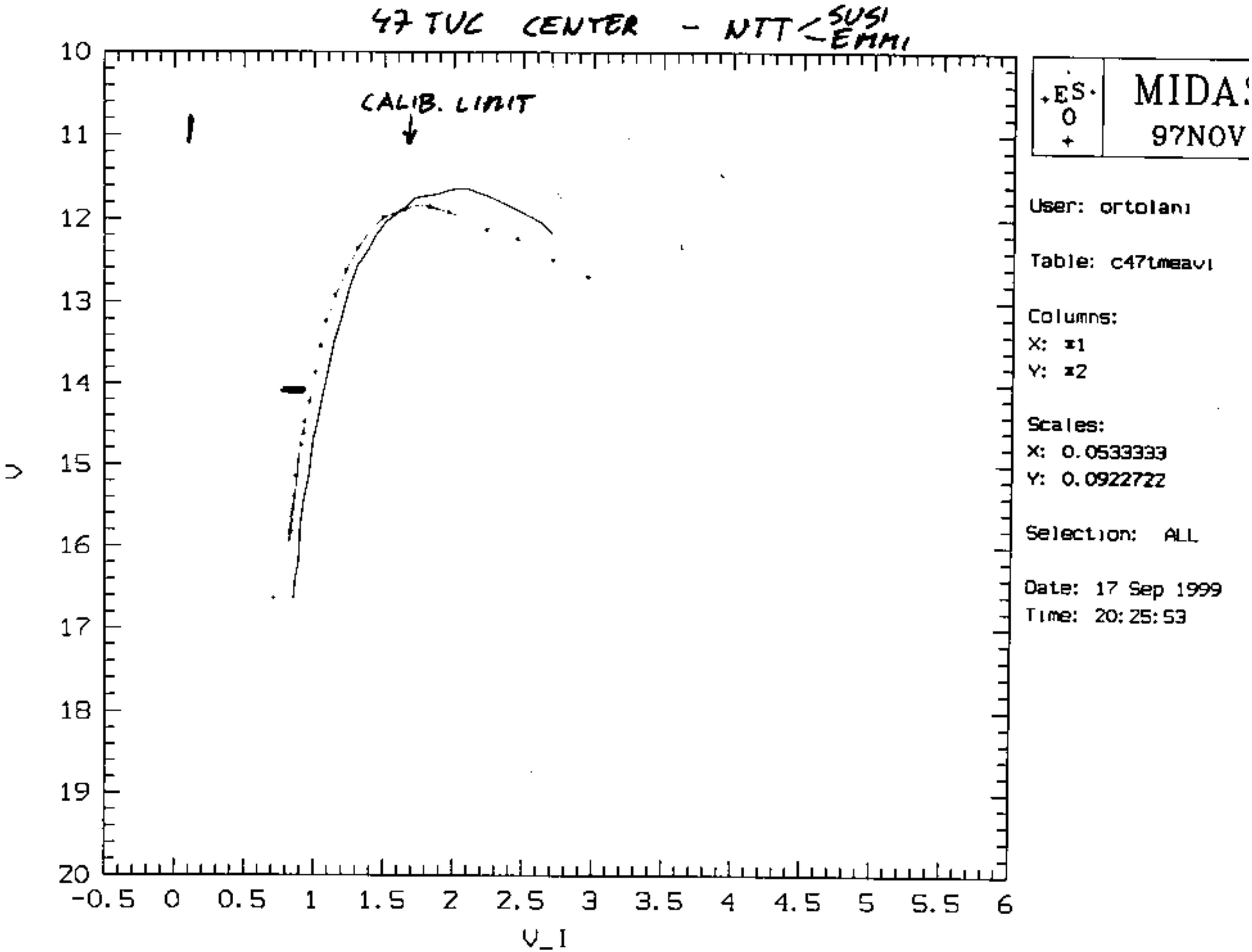


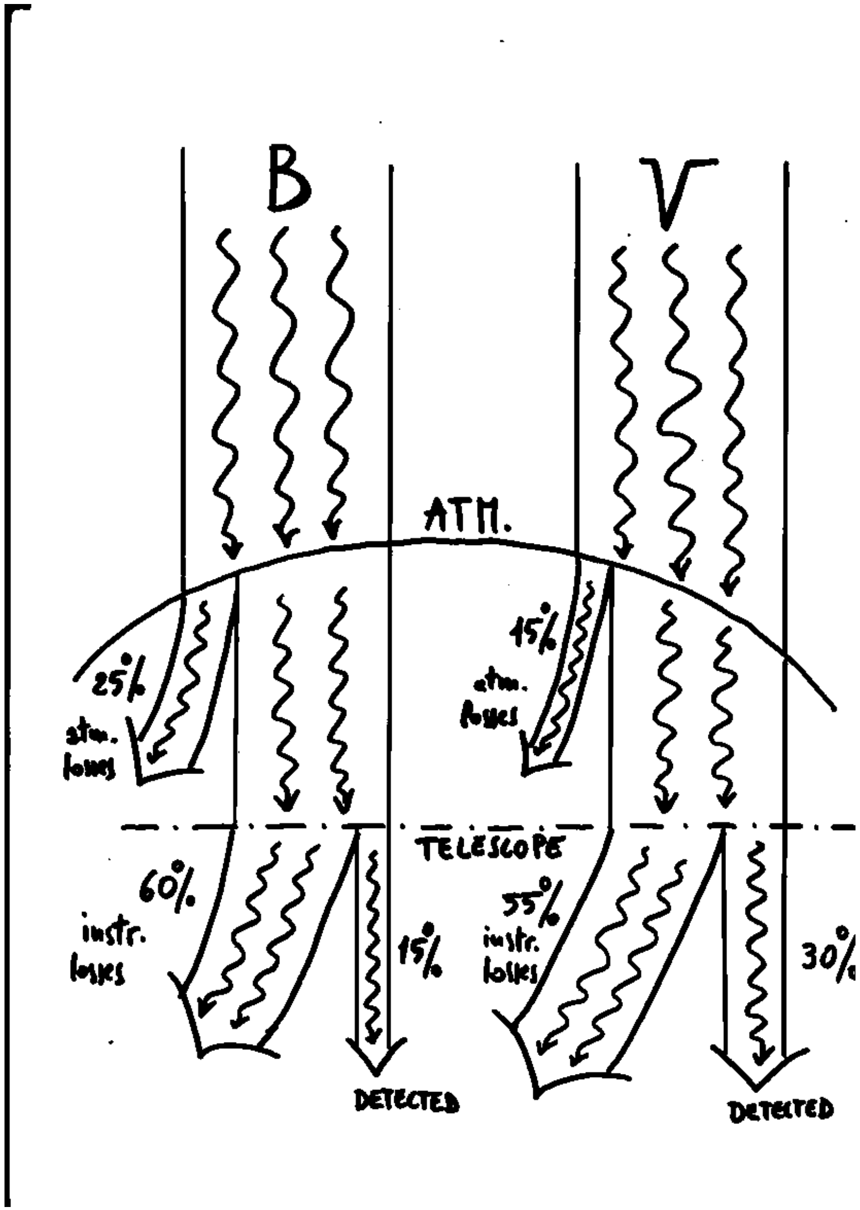
Constant L9638 (B-V = 0.18)   6/1 = 23.516   Kv sw: .20
7/1 = 23.568   .16
8/1 = 23.583   .145
9/1 = 23.563(?)
12/1 = 23.61 (mean 0.17)

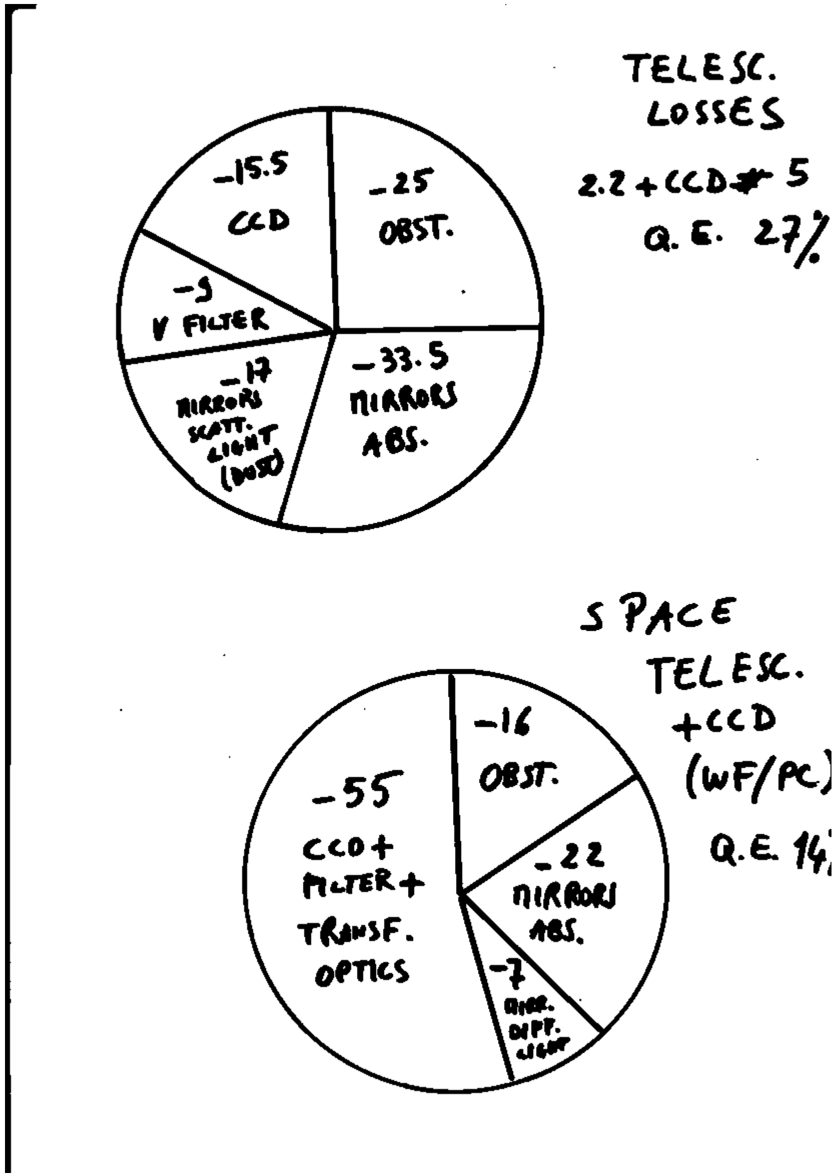
Example of a red blocked UV photometry with a very small slope.




EFOSC + #3 FEBR. 87 (V, B)
V
(+) ← LAST MEAS.
V ~ 0.01 (B-V) + 27.60
ΔV 30s
27.7
27.6
27.5
0.0
0.5
1.0
B-V
B
B = .145 (B-V) + 27.06
ΔB
27.4
27.3
27.2
27.1
27.0
0.0
0.5
1.0
1.5
B-V
MADE IN GERMANY
A 4 210 x 297 mm


47 TUC CENTER - NTT < SUSI EMMI
CALIB. LIMIT
MIDAS
97NOV
User: ortolani
Table: c47tmeavi
Columns:
X: #1
Y: #2
Scales:
X: 0.0533333
Y: 0.0922722
Selection: ALL
Date: 17 Sep 1999
Time: 20:25:53
V
V_I
10
11
12
13
14
15
16
17
18
19
20
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6


B
V
ATM.
25%
atm.
losses
15%
atm.
losses
TELESCOPE
60%
instr.
losses
15%
55%
instr.
losses
30%
DETECTED
DETECTED


TELESC.
LOSSES
2.2 + CCD # 5
Q. E. 27%
-15.5
CCD
-25
OBST.
-9
V FILTER
-17
MIRRORS
SCATT.
LIGHT
(DUST)
-33.5
MIRRORS
ABS.
SPACE
TELESC.
+CCD
(WF/PC)
Q.E. 14
-16
OBST.
-55
CCD+
FILTER+
TRANSF.
OPTICS
-22
MIRRORS
ABS.
-7

General remarks

From the previous examples we have learned a few important things:

1. Observations must be calibrated and models must be transformed into the same photometric system;
2. We need to use as much as possible a “standard” photometric system;
3. If your photometric bandpasses are far from any existing photometric system, you have to calibrate your system starting, for example, from A0 stars (good luck!);

ABSOLUTE CALIBRATION

V = CALIBRATED MAGNITUDE
v = INSTRUMENTAL MAGNITUDE
k_V = COLOR COEFFICIENT
C_V = INSTRUMENTAL CONSTANT $-2.5 \log(\text{STAR}-\text{SKY})$ FOR $V=0$
ΔAP = APERTURE CORRECTION
C_α = EXTINCTION COEFFICIENT ~ 0.2 MAG/AIR MASSE
Δt = EXPOSURE TIME CORRECTION: $2.5 \log(t_1+\delta t)/(t_2+\delta t)$
δt = SHUTTER TIME DELAY
AM = AIR MASSES

$$V = v + k_V (B-V) + C_V + C_\alpha \times AM \times \Delta AP + \Delta t$$

$(V-I)$
$(V-R)$
...

C_α: NEG. ΔAP: NEG. Δt: $\sim$POS.

$AM = 1/\cos(90-h)$
h = height: $\operatorname{sen} h = \operatorname{sen}\delta \operatorname{sen}\varphi + \cos\delta \cos\varphi \cos H$
φ = LATITUDE
δ = DECLINATION
H = HOUR ANGLE (SIDERAL TIME - RIGHT ASCENSION)

CALIBRATION EQUATIONS

FROM STAND.
$$\begin{cases} B = b + K_B (B-V) + C_B + \dots \text{(ATM. EXT.)} \\ V = v + K_V (B-V) + C_V + \dots \text{(ATM. EXT.)} \end{cases}$$

WITH B, V MAGNITUDES IN THE STANDARD SYSTEM

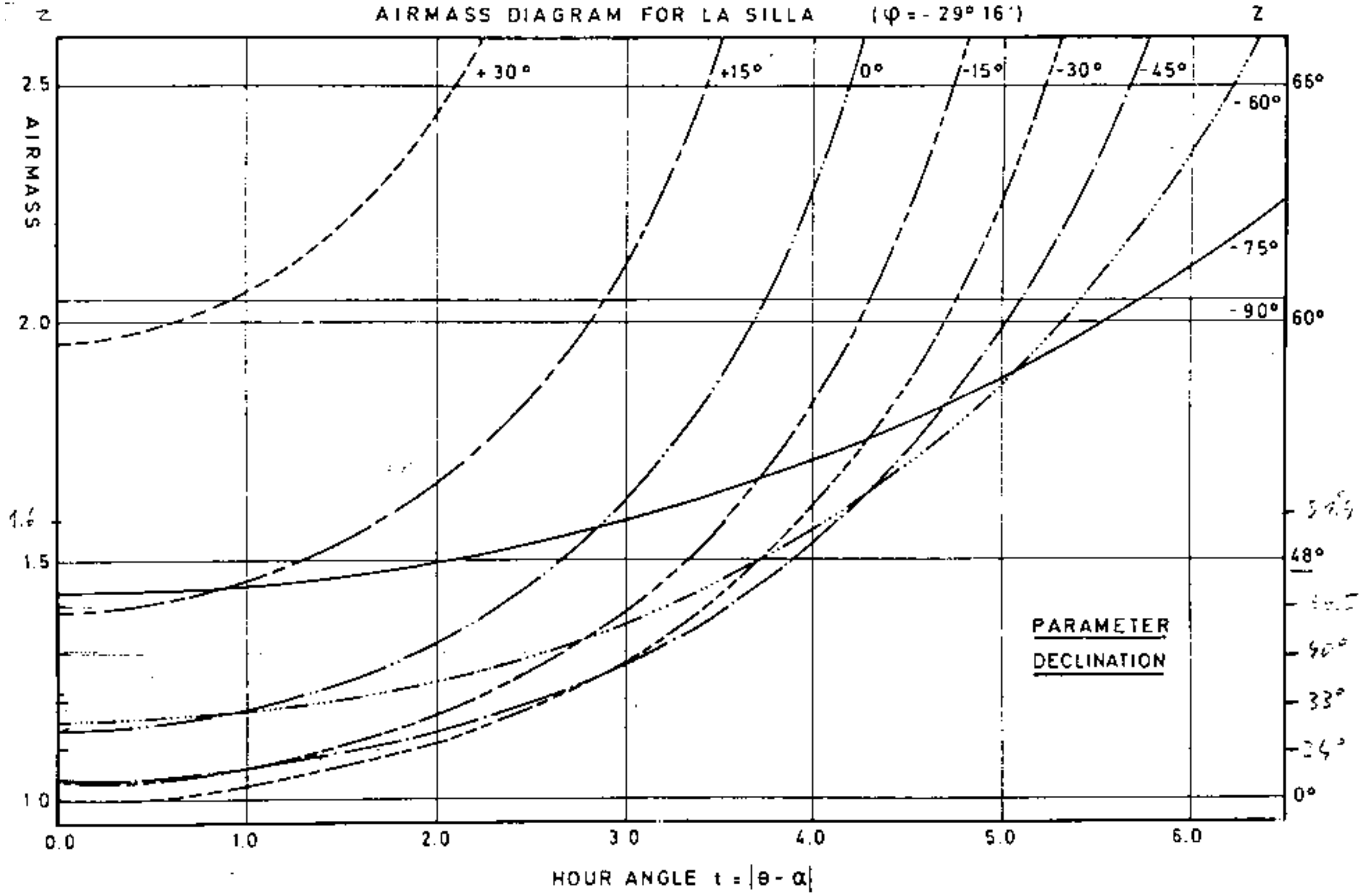
b, v INSTRUMENTAL MAGNITUDES

K_V, K_B, C_V, C_B CONSTANTS

$$\rightarrow B-V = b - v + (B-V)(K_B - K_V) + C_B - C_V$$

$$B-V = (b-v)\frac{1}{1+K_V-K_B} + (C_B - C_V)\frac{1}{1+K_V-K_B}$$

WHERE $\frac{1}{1+K_V-K_B} \gtrsim 1$



AIRMASS DIAGRAM FOR LA SILLA (φ = - 29° 16')
z
Z
AIRMASS
2.5
2.0
1.5
1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
HOUR ANGLE t = |θ - α|
+30°
+15°
0°
-15°
-30°
-45°
-60°
-75°
-90°
66°
60°
48°
33°
0°
PARAMETER
DECLINATION

CONCLUSIONS

An important conclusion is that we always need to observe our objects in two bands. From a physical point of view this means that we need a parameter in order to define the shape of the spectrum. Then the corrections corresponding to their spectra will be applied in order to transform their "instrumental magnitude system" into the system defined by the standard stars.
Objects observed in a single band cannot be calibrated if their spectral type is not known. Possible errors are of The order of magnitude of the slope of the calibration line.

HOWEVER:

1) **peculiar spectra objects cannot be properly calibrated (for example multiple black body spectra, late type stars with peculiar metallicities…);**

2) **Very red or very blue stars are very difficult to calibrate because there are very few good standard stars with colors below B-V=0.4 or above 1.2. Stars outside this interval are often variables (red stars are long period variables, blue stars are often pulsating stars within the instability strip). The reddening should be also considered because it changes the shape of the spectra. Deviations from the linear interpolation are expected.**

Recent Tests indicates errors up to 0.3 magnitudes in the V-I color from the WFI at 2.2.

SUGGESTIONS FOR AN ACCURATE CALIBRATION

- **CAREFULLY CHECK THE FLAT FIELDS, COMPARE SKY AND DOME FLATS**
- **CHECK THE SHUTTER TIMING MEASURING IN REAL TIME THE STANDARD STARS. DELAYS UP TO 0.5 s SHOULD BE EXPECTED ! THIS IS A REAL PROBLEM FOR BRIGHT STARS.**
- **BE CAREFUL TO HAVE THE PEAK OF THE STANDARD STARS AT LEAST 10% BELOW THE SATURATION LIMIT (50% RECOMMENDED). DEFOCUSED IMAGES GIVE MUCH MORE ACCURATE MEASUREMENTS (BUT…)**
- **REPEAT THE OBSERVATIONS OF THE STANDARDS, POSSIBLY INCLUDING DIFFERENT EXPOSURE TIMES AND CHANGING THEIR POSITIONS ON THE CCD, AND MEASURE THE INSTURMENTAL MAGNITUDE IN REAL TIME.**

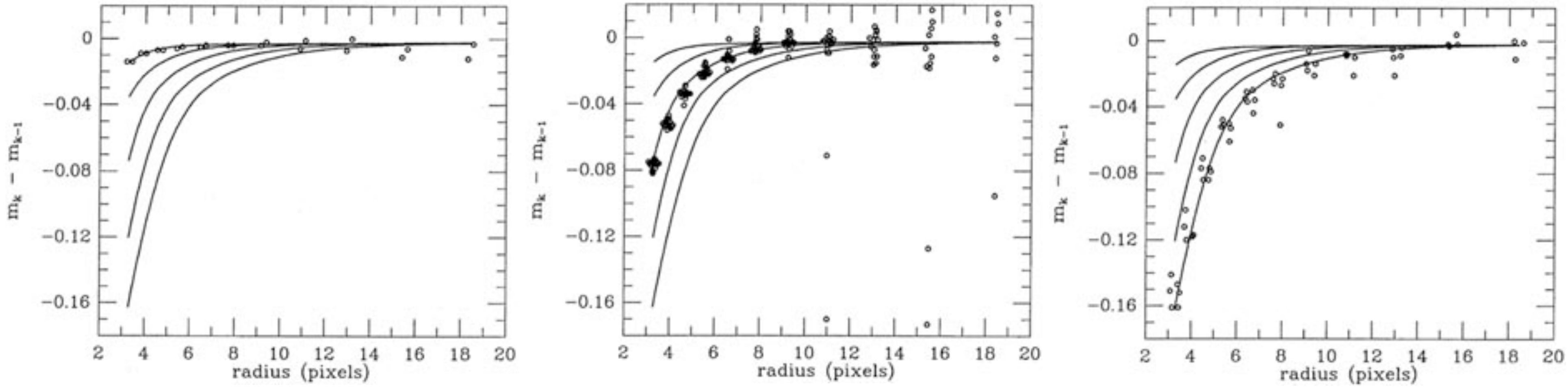
THE NEXT STEP: THE APERTURE CORRECTION

OR

HOW MUCH LIGHT OF THE STANDARD vs. OUR STARS IN INCLUDED IN THE MEASUREMENTS ?

It could be a difficult step if:

- **The standard stars have been defocused by a large amount;**
- **The seeing of the standards is significantly different from the stars to be calibrated**
- **The target stars are in very crowded fields**



Examples of growth curves for different seeing conditions, from the same observing run. In crowded fields the growth curves could be noisy due to blends.

In order to improve the correction, one can fit to the aperture photometry differences a model, or use diagnostic diagrams.

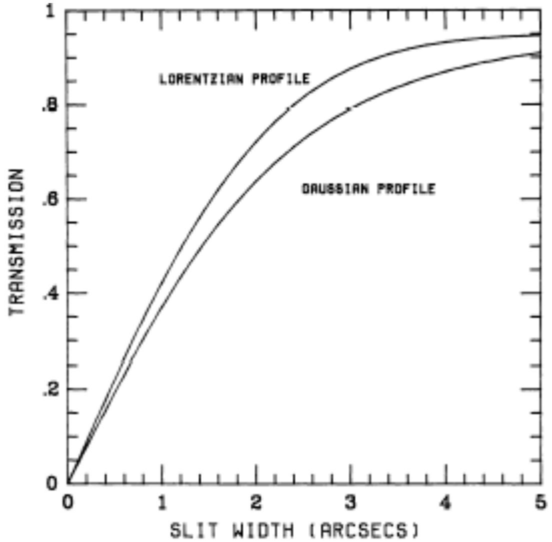


FIG. 8–Transmission of a long slit for a FWHM seeing of 2.0 arc secs, for Gaussian and Lorentzian point-spread functions.

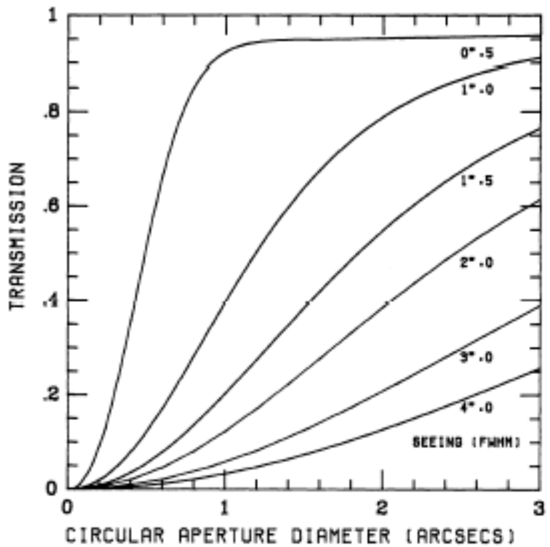


FIG. 6–Small circular aperture transmission as a function of seeing FWHM (in arc secs).

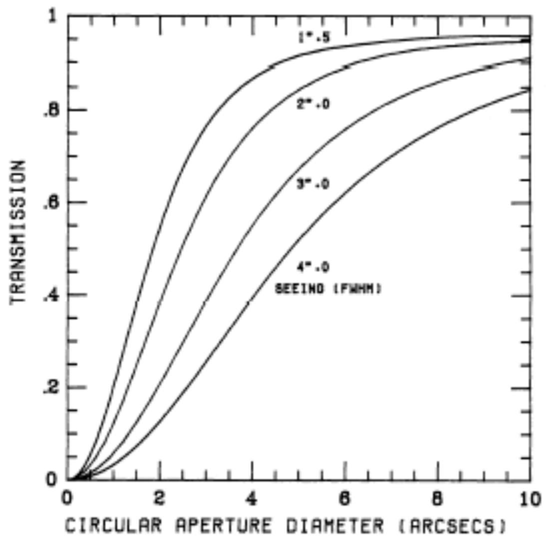


FIG. 7–Large circular aperture transmission as a function of seeing FWHM (in arc secs).

Calibration errors

There are several sources of calibrations errors

1. Photometric errors of the standard stars, including variability;
2. Linearity deviations;
3. Reddened standard stars;
4. Residuals from flat fields
5. Shutter timing delay or patterns;
6. Non linear color equations
7. Sky transmission fluctuations
8. WRONG APERTURE CORRECTIONS IN CROWDED FIELDS

Following Stetson (2005) the shutter timing can be the major source of errors even at modern telescopes. SUGGESTIONS: multiple observations of standard stars with different exposure times! Remember that the machanical shutters