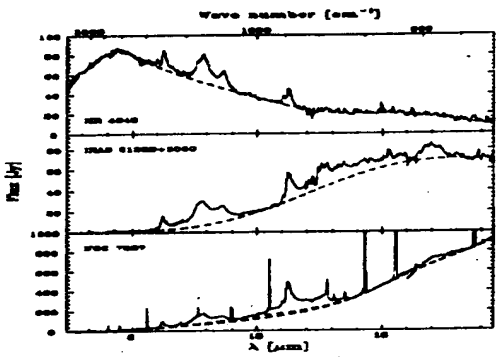
esa



A Users' View of

ISO-SWS CALIBRATIONS

with pointers to the IA CAL file system

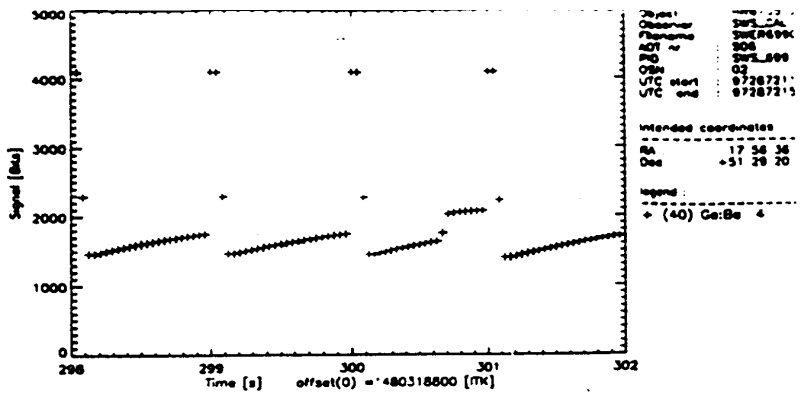
I. Quick look at the ERD ⟶ SPD calfiles

II. Wavelength Calibration
- Parameters, measurements, drift

III. Instrumental Profile (IP)
- Point & extendted source profiles
- Wing deviations
- Fabry-Perot IP and leakage

IV. Resolving Power
- Observed and model spectral resolutions S02,S06,S07
- Observed S01 ratios

V. Photometric Calibration
- Absolute responsivities
- RSRF
- SC pointing, beam profiles
- Error budget, incl. dark currents, memory



Flagging data

Cal-G file 4 → Correction for Amp limits { Min = 0, Max = 4095 (saturn)

Cal-G file 3 → Flagging resets { Reset "cutout"

Cal-G file 1 → Electrical Cross-talk removal { Dimensionless, near unity, X-talk matrix 12×12 (TLT + flight)

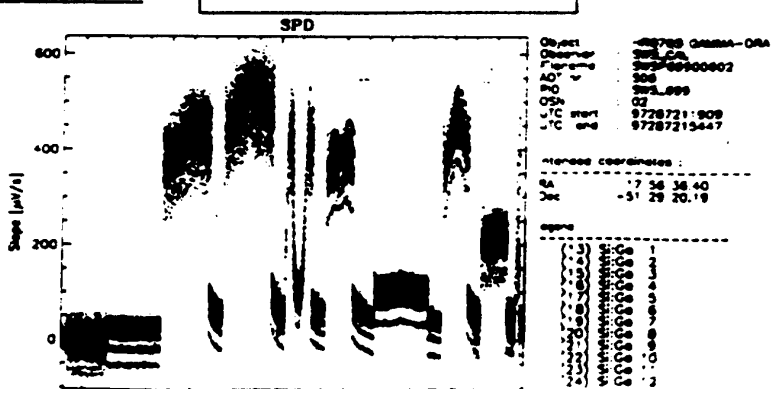
Cal-G file 2 → Measurement Linearization { 0-voltage pt., reset pulse aftermath

Cal-G file 6 → Deglitching { Reject levels (flight) TA tables

Cal-G files 5,7 → Conversion to voltages { Slope calculation by gain, & accounting for non-ram signal, dark current, & readout

Photocurrent extraction

Cal-G files 16,18,23,24 → Assign λ and write data →



WAVELENGTH CALIBRATION

CAL16A-E Aperture Offsets, Element Offsets, Grating Constants, Telescope area, Polynomial coefficients (5th order polynomial)
CAL18 λ-dep F-P gaps
CAL23 Detector band λ ranges modified slightly since launch
CAL24 Aperture λ ranges

$$\lambda \times \frac{N}{D} = \sin(\theta + \beta) + \sin(\theta + \delta)$$

θ = angle of incidence at current scanner setting (or LVDT, $\sim$ 1/8 res. element)
β = offset angle from aperture entrance or internal source to optical axis
δ = offset angle from detector element to optical axis
D = grating constant (groove spacing)
N = spectral order.

2 internal sources (coiled filaments + filters) $\longrightarrow$ 60 fringes in LW section, 250 fringes in SW section. One source for the F-P.

β, δ, LVDT-θ relationship (5^{th} order poly) determined preflight, quickly restored after launch to get new offset angle of internal sources wrt LVDT.

↑ external calibrators
PNe, planets

Table 1. Lines used for the grating wavelength calibration

SW section Ion	Wavelength [μm]	Ref.	LW section Ion	Wavelength [μm]	Ref.
[Mg IV]	4.488	a	[Ne II]	12.81355	b
[Ar VI]	4.527	a	[Mg V]	13.5213	d
[Mg V]	5.608	a	[Ar V]	13.1022	d
[Ar II]	6.98527	b	[Ne III]	15.5551	d
[Ar III]	8.99103	c	[S III]	18.7125	c
[Si IV]	10.5105	a	[Ne V]	24.3175	d
H recombination lines			[O IV]	25.8903	d
			[S III]	33.4810	d
			[Ne III]	36.0135	d

[a] Schmid-Burgk 1982, [b] Yamada et al. 1985,
[c] Kelly & Lacy 1995, [d] From FP observations

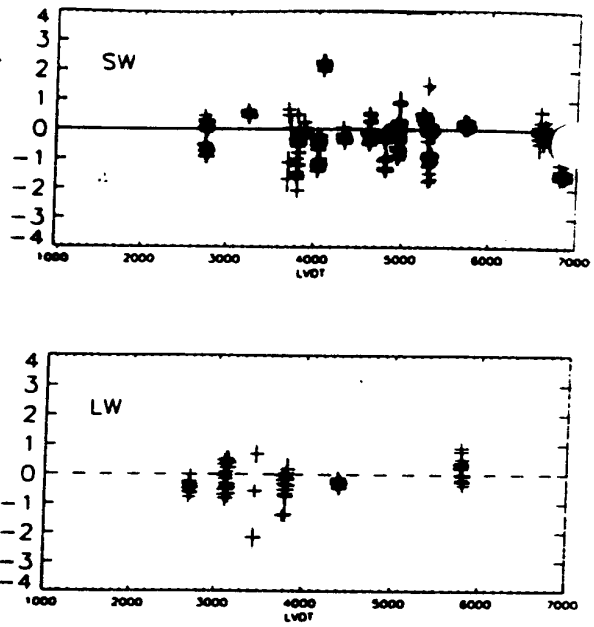


Fig. 1. Example residuals of the wavelength calibration in instrumental units LVDT from observations of Planetary Nebulae. Top figure: SW grating section using H recombination lines in NGC 7027, and ionic lines in IC 2501, Bottom figure: LW grating section, using ionic lines in IC 2501 (for wavelengths see Table 1).

Valentijn et al. 1995, A&A

Table 2. Observed external wavelength standards for the FP wavelength calibration

Line	Vac. Wavelength [μm]	Meas. Offset [μm]	Object.
[Ne II]	12.81355±(2)[a]	+(4)	NGC7027
[Mg V]	13.52120±(2)[b]	−(6)	NGC7027
H_2 S(1)	17.034835±(6)[c]	−(60)	Saturn
H_2 S(1)	17.034835±(6)[c]	+(50)	Jupiter
H_2 S(0)	28.21883±(2)[c]	−(5)	Saturn
H_2 S(0)	28.21883±(2)[c]	+(9)	Jupiter
H_2O	29.83671±(1)[d]	−(18)	W Hya
H_2O	31.77205±(1)[d]	+(2)	W Hya
HD R(2)	37.70154±(1)[e]	−(1)	Jupiter
HD R(2)	37.70154±(1)[e]	+(20)	Saturn
H_2O	40.69087±(1)[d]	−(21)	W Hya

Numbers in brackets relate to last decimals
[a] Yamada et al. 1985, [b] Kelly & Lacy 1995
[c] Jennings et al. 1987, [d] HITRAN [e] Ulivi et al. 1991

ISO-SWS CALIBRATIONS

Wavelength Calibration - 2

PV Update $\Longrightarrow$
LW: $\sim$ 1/10 r.e. ($\lambda/\delta\lambda \sim$ 16000-8000)
SW: $\sim$ 1/5 r.e. ($\lambda/\delta\lambda \sim$ 5000-12000)
FP: $\lambda/\delta\lambda \sim 10^5$.
Improved λ_0 of 29 ionic lines (Feuchtgruber et al. 1996)

- ***$LVDT-\theta$ relationship may drift in practice with change in effective thickness of filters for internal calibrators, or change in position of light sources.***

- ***Has it?***

A little bit... ΔLVDT about 1.5-2 since rev28,32 calibrations.

$\Longrightarrow$ Rev356 update of first 2 coeff's of LW grating polynome.
$\Longrightarrow$ Rev370 update of all 6 coeff's for SW section.
$\Longrightarrow$ Update uplink tables to optimize F-P light to peak of instrumental profile.
$\Longrightarrow$ Updates in revs 475-479, 669-670.

5

Internal Source

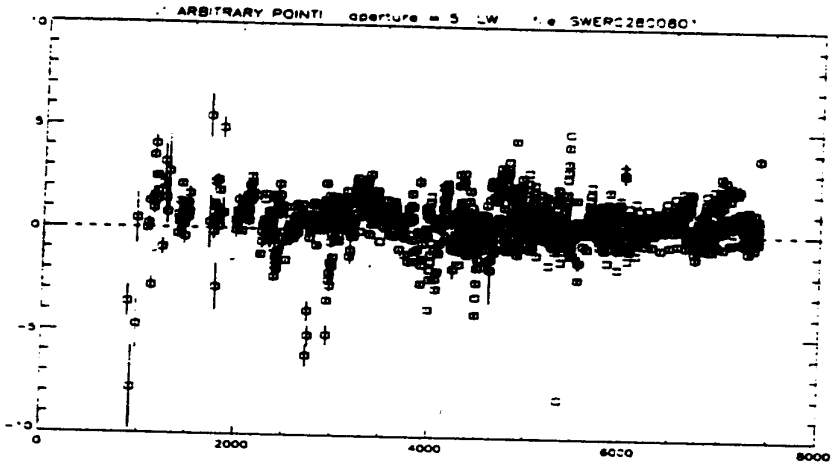


Figure 1: Misalignment of the peaks (ΔLVDT) versus LVDT for the grating calibration scan in revolution number 28.

External Source NGC 7027

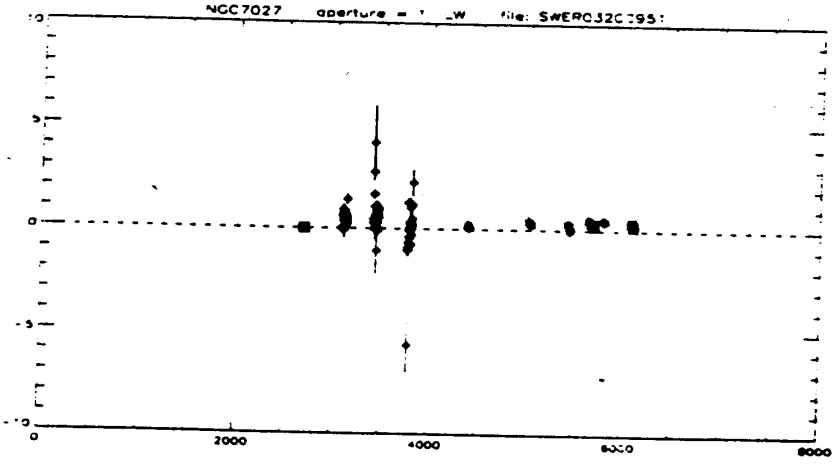


Figure 2: Misalignment of the lines of NGC 7027 in revolution number 32.

Internal

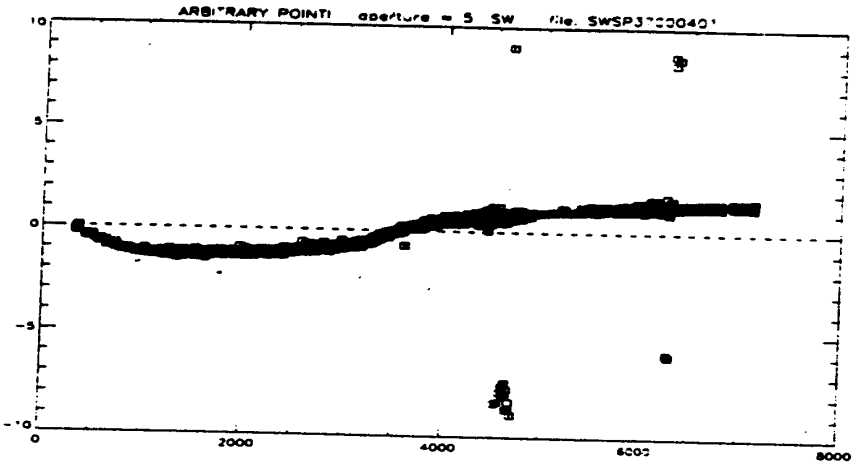


Figure 10: Displacement of the peaks (ΔLVDT) of SW detectors versus LVDT for the grating calibration scan in revolution number 370 wrt. the wavelength calibration of revolution number 32.

External

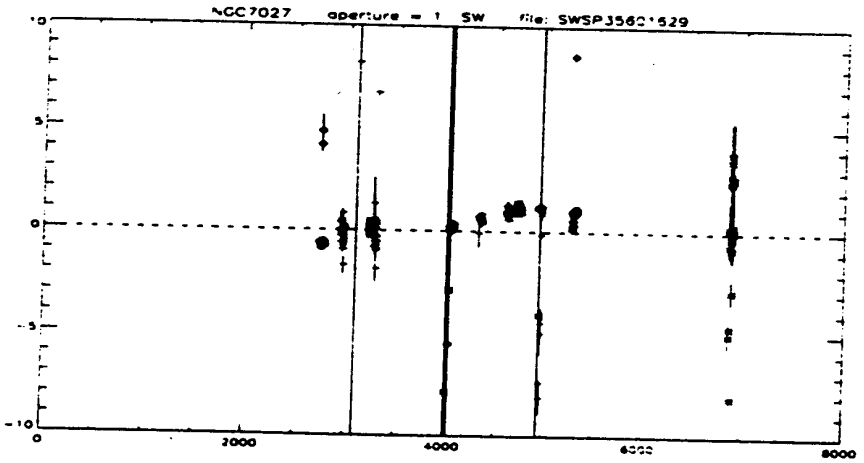


Figure 11: Displacement of the lines in NGC7027 in revolution number 356 versus LVDT wrt. the calibration of revolution number 32.

Exercise for the student: CAL16E contains coeffecients for $\theta = A_0 + A_1 \mathrm{LVDT} + A_2 \mathrm{LVDT}^2 + \cdots$, and can be used to look at the time-dependent changes to our wavelength calibration.

```
IA3 TEST> c16e=readcal('16e')
readcal: IAS_ROOT:[CAL]cal16e_014.fits
IA3 TEST> showstruct,c16e
(1)
   |---TYPE<Strng>(1)
   |-HEADER<Strng>(1)
   |---DATA<Struc>(6)
                    |-SW<Doubl>(1)
                    |-LW<Doubl>(1)
IA3 TEST> print,c16e.data(0:5).(0)
      0.46334359     -0.27706605     0.0048576170     0.0064124302
 -0.00037031178    -0.0052517322
```

INSTRUMENTAL PROFILE (IP)

CAL26 Grating & F-P IP database (TBD)

The IP gives the instrumental spectral response when scanning a line which is intrinsically much narrower than the profile itself. Grating and F-P IPs to $< 5\%$ peak measured on point & extended sources, checked for leakage.

Grating IP on pt and extended sources (eg NGC7027, DR21-E/W, IC2501, Sgr A*)
S02 & S06 = 6 samples / FWHM stepsize 1, each detector sees 20 resolution elements per scan for wing-wing coverage.

ON-source, *the grating IP is Gaussian to a very high degree of accuracy for* **point** *and* **extended** *sources.*

OFF-source, *unresolved lines deviate from on-source profile centroid, with* **NO** *degradation of resolution. Flux-loss according to beam profiles.*

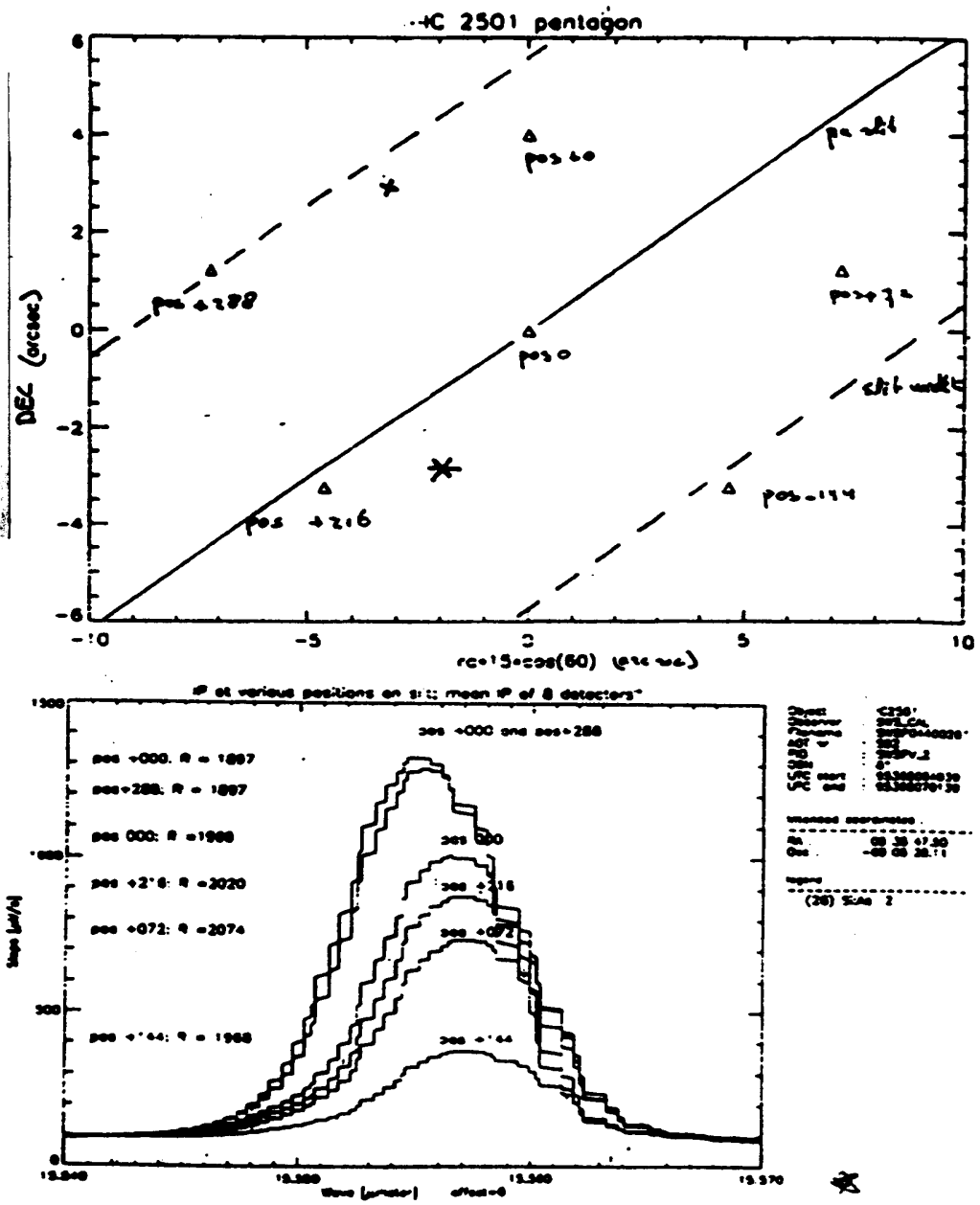


Figure 4.12: Changes in SWS instrumental profile and resolving power R with the position of the source in the slit.

see IDUM p. 60

F-P IP, and Grating IP as seen by the F-P:

- F-P IP: See *Observer's Manual*. No full re-derivations inflight due to required velocities ($\leq$ 10 km/s) + high signal.

- Grating IP seen by the F-P (leakage by neighboring F-P orders): CAL12 Position - gap relations of scanning F-Ps
  Broad grating IP and insufficient pre-filtering of undesired F-P orders by the grating can result in leakage of these orders into F-P spectra. This is worst for extended or crowded regions ... worst case plotted in *Observer's Manual* (fully extended in ILT).

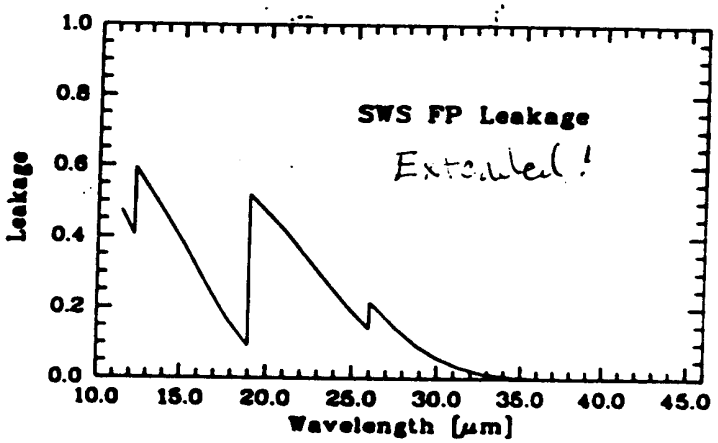


Figure 5.13: SWS Fabry-Pérot leakage. Leakage is defined here as the fraction of the total detected signal that originates in unwanted Fabry-Pérot orders. Preliminary data shown here are based on extrapolation from measurements at a few wavelengths. A better characterization is expected from in-orbit calibration

Instrumental Profile - 2

Departures from Gaussian profiles have been observed in wings of a few unresolved lines:

- Excess ~3-5% of peak flux in the blue wing.
- Slight depression $< 2\%$ peak flux in red wing.
- Likely due to some internal reflections, pointing-dependent. Velocity dependence not yet known, bi-monthly NGC6543 S02 profiles being analyzed by SIDT.
- Resolved lines tend to exhibit the bumps less strongly

15

SPECTRAL RESOLUTION

CAL19 FWHM vs λ by AOT (S02,S06,S07)

Measurements of Grating + F-P spectral resolutions taken from same IP calibration sources (point and extended).

S02,S06: Observed resolutions match predictions from optical model of SWS (coded into IA module RESOLUTION) well.

S01, all speeds: Inflight measurments of NGC7027 and NGC6543 to in progress to confirm theoretical resolving power at various S01 scanning speeds. → upgrade!

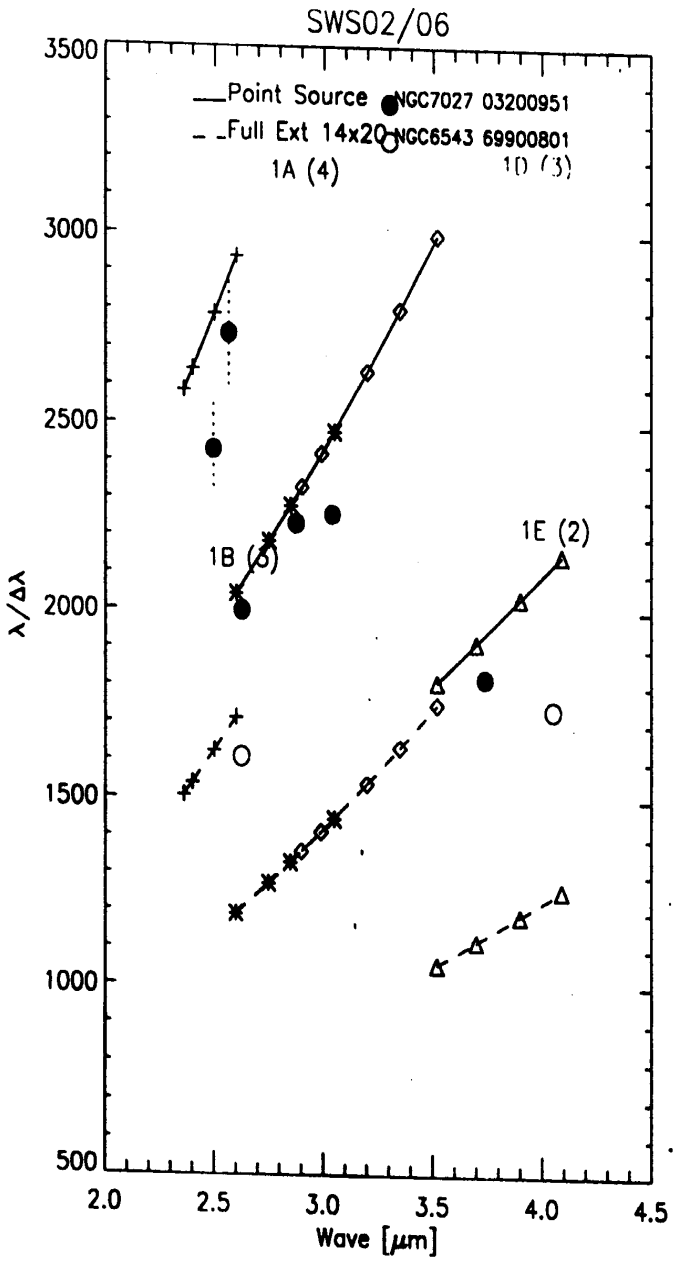
Table 6.3: Possible combinations of reset time t_r, step size L_s in scanner steps, and number of scans n_{scan} for each of the SWS AOT's

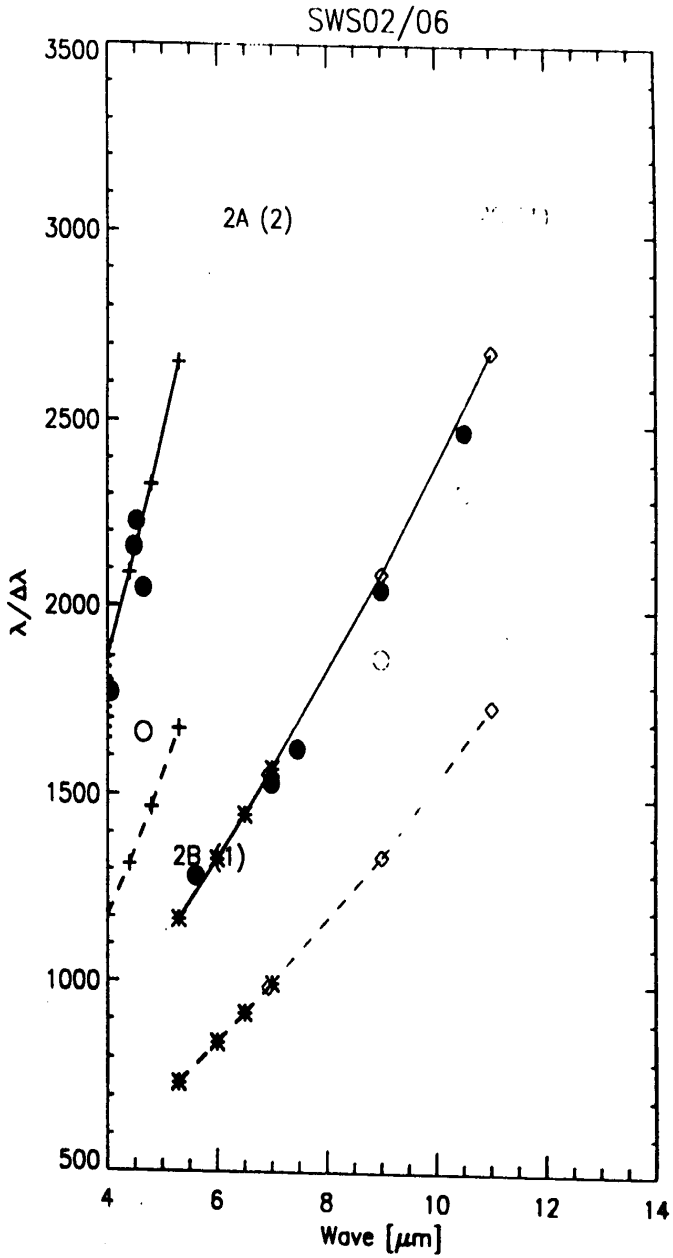
AOT	Band						notes
SWS01	all	t_r	1	2	2	2	
		L_s	32	32	16	8	a
		n_{scan}	2	2	2	2	1 up, 1 down
		n_{int}	24	24	24	24	b
		resolution	R/8	R/8	R/4	R/2	c
		res.(1 sec)	R/8	R/4	R/2	R	? d
		duration	12.7	25.5	50.9	101.9	minutes

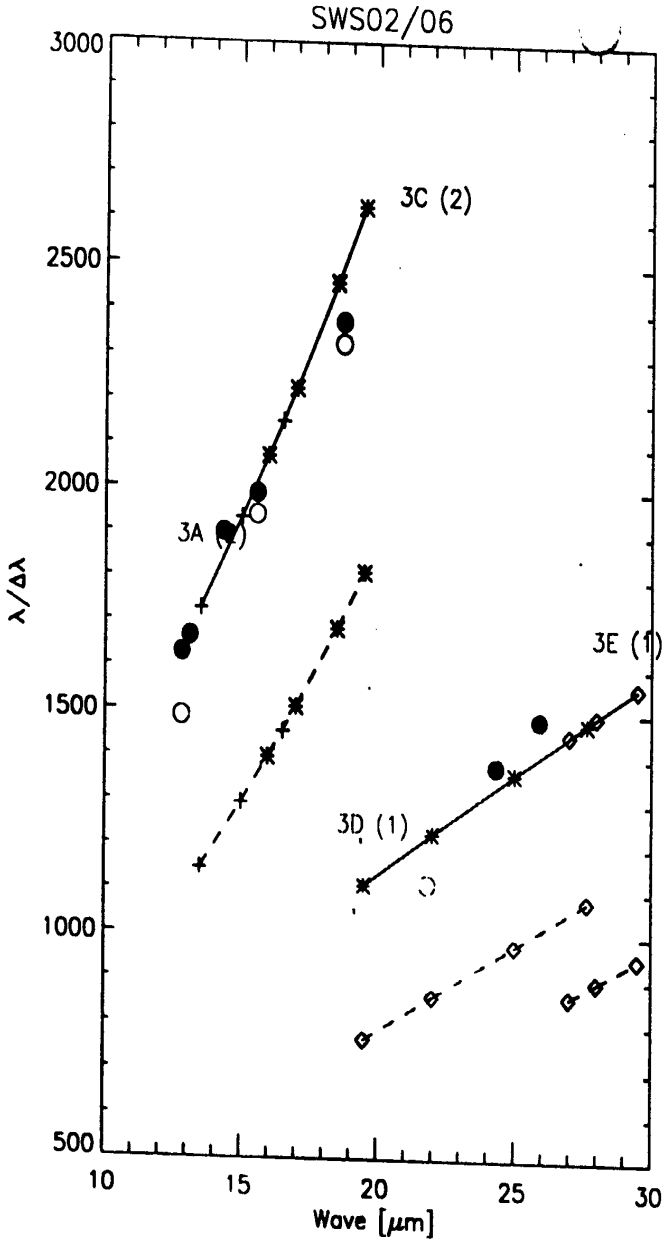
From OM.

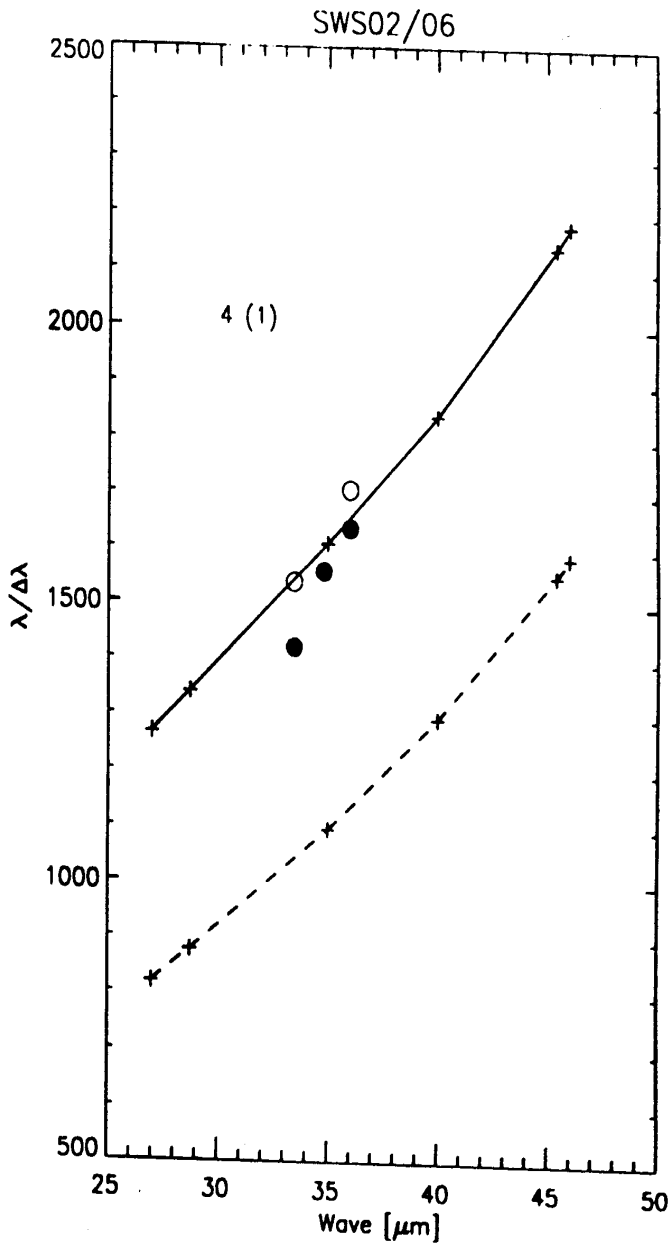
→ R/5 R/5 R/2.5 R/1.7

Resolution "enhancement" of SW1-4, SW1-3 in progress.


SWS02/06
Point Source NGC7027 03200951
Full Ext 14x20 NGC6543 69900801
1A (4)
1B (3)
1E (2)
λ/Δλ
Wave [μm]


SWS02/06
2A (2)
2B (1)
λ/Δλ
Wave [μm]


SWS02/06
3C (2)
3A (1)
3E (1)
3D (1)
λ/Δλ
Wave [μm]


SWS02/06
4 (1)
λ/Δλ
Wave [μm]

CAL25 Flux Calibration (RSRF)

Gain factors for external signal outside of key passbands supplied by RSRFs, first derived from lab measurement on fully extended thermal sources maximum grating and F-P resolutions $\longrightarrow$ CAL25. Inflight updates:

1. Broad-band corrections for point-source diffraction losses and non-linear instrument/telescope effects.
2. Cross-talk corrections to original ILT measurments.
3. Finer structure improvements by iteration between cal observations and model atmospheres of K-M giants, Vega, and Sirius.

Full RSRF characterization continues into post-Ops...

CAL?? Spacecraft Pointing, Beam Profiles

Several dedicated beam profile measurements on γ Dra, α Boo, η Car, and NML Cyg (all very bright) since PV establish sharply peaked, λ-dependent profiles $\Longrightarrow$ SWS is very sensitive to SC pointing! 5″ APE $\approx$ 10-25% signal loss.

ISO Attitude & Orbit Control System modes **much better** than specifications:

0.5″ jitter ($\leq$ 2.7″ spec)
3.5″ APE rev093 - rev368 ($\leq$ 11.7″ spec!!)

$\leq 1.5''$ APE > rev369 (STR recalibration)

Beam profile and RSRF variations with pointing offset for $2.4 < \lambda < 27$ μm measured in former APE box of $4''$ with AOT1-like CUS observations of α Boo (rev640):

4. Weekly quick dark current measurements to monitor detector dark levels and dark noise (outside AOT environment) ⟶ **CAL21.** Low and high limits have been defined so that dark currents for different gains are in limits, and out-of-limits dark currents are those with rather unusual values or strongly affected by memory effects after the observation of an intense source (mainly bands 2 and 4) or particle events (mainly band 4).

For reset interval 1:

```
IA3 TEST> c21_1=readcal('21_1')
readcal: IAS_ROOT:[CAL]cal21_1_011.fits
IA3 TEST> showstruct,c21_1
% Compiled module: SHOWSTRUCT.

(1)
   |---TYPE<Strng>(1)
   |-HEADER<Strng>(1)
   |---DATA<Struc>(52)
                       |-----DETECTOR<Long >(1)
                       |-DARK_CURRENT<Float>(1)
                       |---DARK_NOISE<Float>(1)
                       |----LOW_LIMIT<Float>(1)
                       |---HIGH_LIMIT<Float>(1)
```

The dark current and dark noise [μV/s] for detector 5 is

```
IA3 TEST> print,c21_1.data(5).(1),c21_1.data(5).(2)
      11.4291       2.21417
```

Upper and lower limits on the dark level is

```
IA3 TEST> print,c21_1.data(5).(3),c21_1.data(5).(4)
      26.0842       9.91577
```

During dark current subtraction, DARK will tell you if the dark current in this detector at this reset time is not within these limits. *This is an indicator that this detector may be photometrically unstable.*

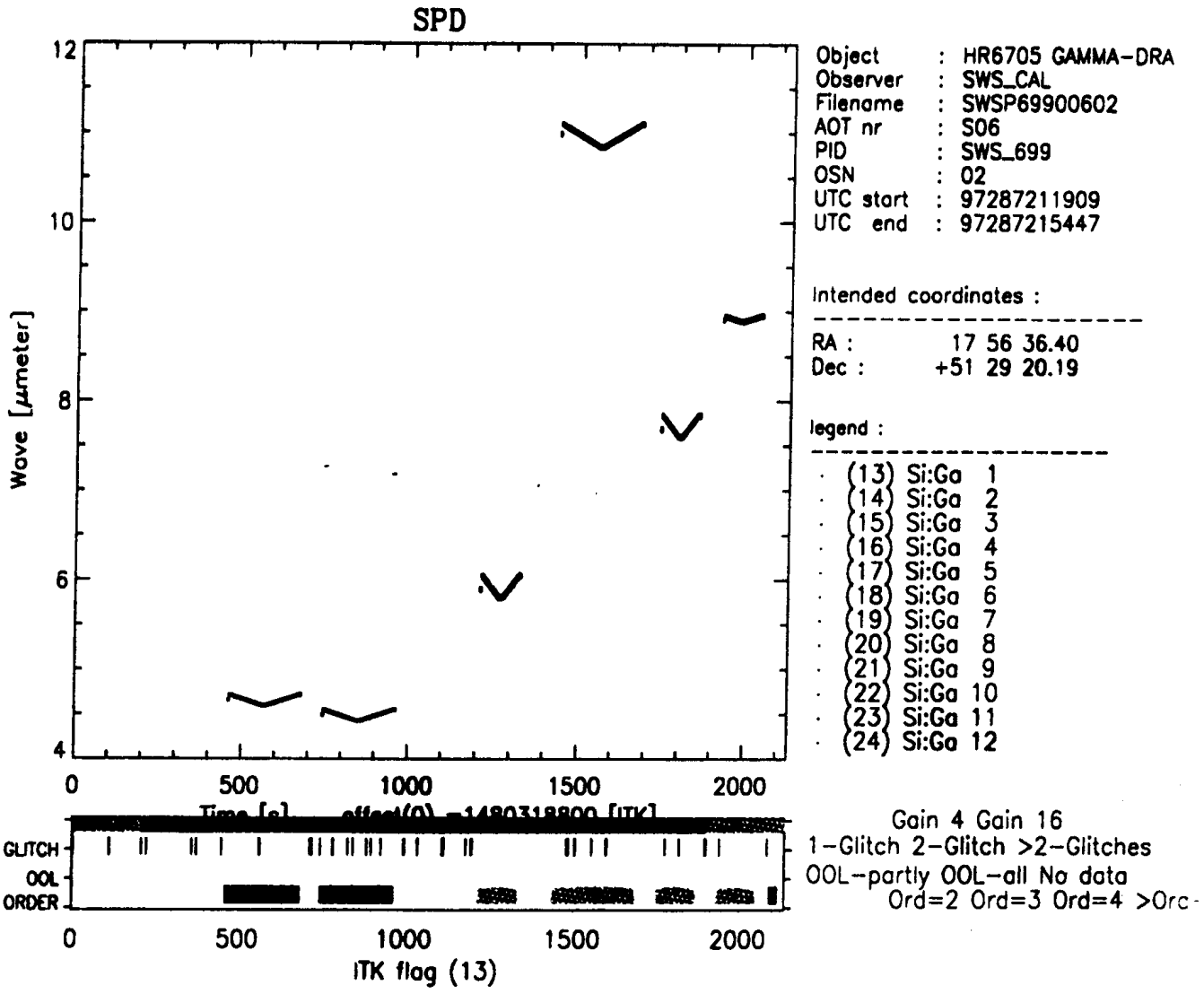
What to do?

- Interactive dark current subtraction;
- Try CAL21 dark values (with appropriate gain correction);
- Offset correction to mean of other detectors at AAR level (depending on total incoming signal + dark signal);
- Throw it away.

Careful... CAL21 is measured in calibration observations at gain 16, while darks within the AOT environment may be taken at different gains. CAL21 is used for monitoring and trend studies, *not* in the pipeline for signal correction, and interactive dark current subtraction is not consistent with calibration stream.

5. Weekly quick checks of detector response to internal stimulators (outside AOT environment) $\longrightarrow$ CAL22.
6. 3-month check of detector memory from long exposure to internal stimulators (outside AOT environment).
7. Validated by independently calibrated scans of standards, and checks of archived science observations (all AOTs).

19h


SPD
Wave [μmeter]
12
10
8
6
4
0
500
1000
1500
2000
GLITCH
OOL
ORDER
ITK flag (13)
Object : HR6705 GAMMA-DRA
Observer : SWS_CAL
Filename : SWSP69900602
AOT nr : S06
PID : SWS_699
OSN : 02
UTC start : 97287211909
UTC end : 97287215447
Intended coordinates :
RA : 17 56 36.40
Dec : +51 29 20.19
legend :
(13) Si:Ga 1
(14) Si:Ga 2
(15) Si:Ga 3
(16) Si:Ga 4
(17) Si:Ga 5
(18) Si:Ga 6
(19) Si:Ga 7
(20) Si:Ga 8
(21) Si:Ga 9
(22) Si:Ga 10
(23) Si:Ga 11
(24) Si:Ga 12
Gain 4 Gain 16
1-Glitch 2-Glitch >2-Glitches
OOL-partly OOL-all No data
Ord=2 Ord=3 Ord=4 >Orc
PMORRIS / 7-Nov-1997 14:50:08

PHOTOMETRIC CALIBRATION

CAL13 Flux Calibration (absolute responses)

Calibration strategy:

1. Absolute conversion factors derived in certain passbands, aka "key" λ.
2. Weekly observations (**S06**, S01, S07) of stellar sources and/or solar system objects with reference levels set by IRAS, ground-based and airborne spectrophotometry (ISO GBPP, KAO, etc.).
3. Detector output from external signals, internal photometric (drift) checks, and "relative fluxes" (gain factors) ⟶ **CAL13**, later called by FLUXCON.

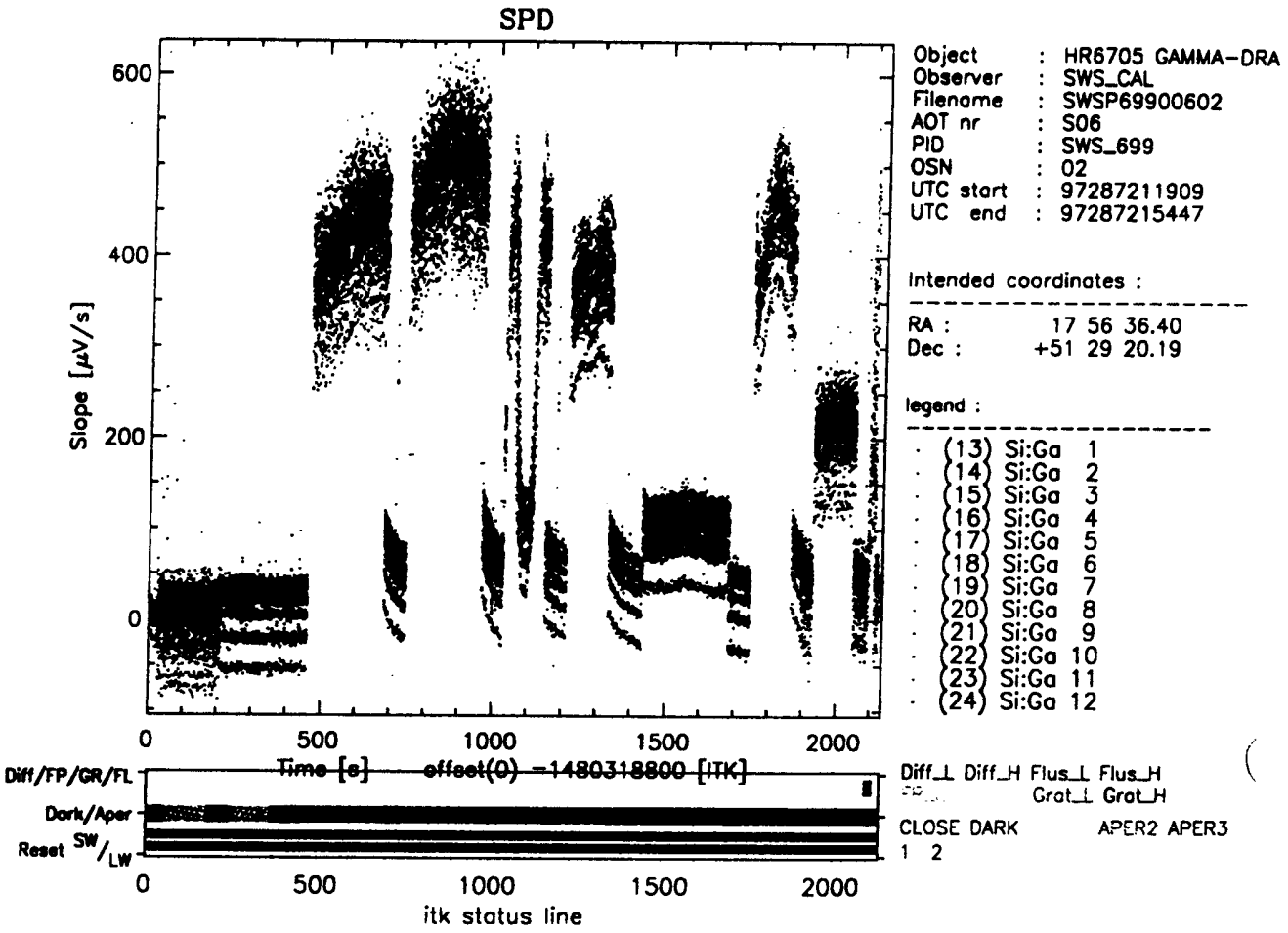
* γ Dra
α Boo
β Peg
⋮
} K III

α Lyr
Sirius A
} A3V

Uranus
Ceres
Pallas

spd = antimem (swsp)
spd = dark (spd)
spd = respcal (spd)
spd = velcor (spd)

15ja



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=2

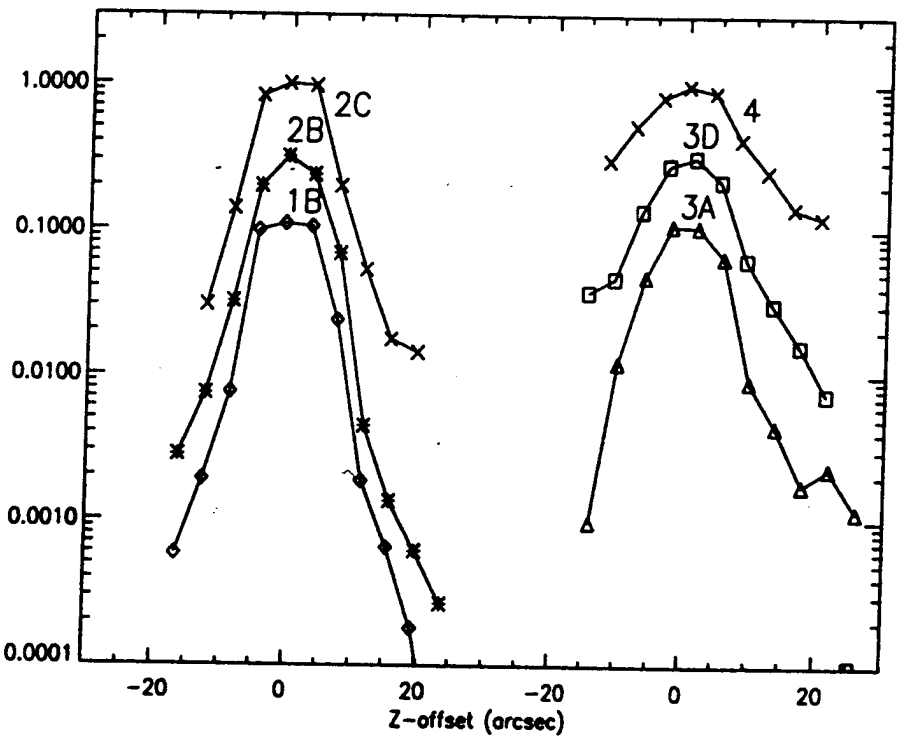
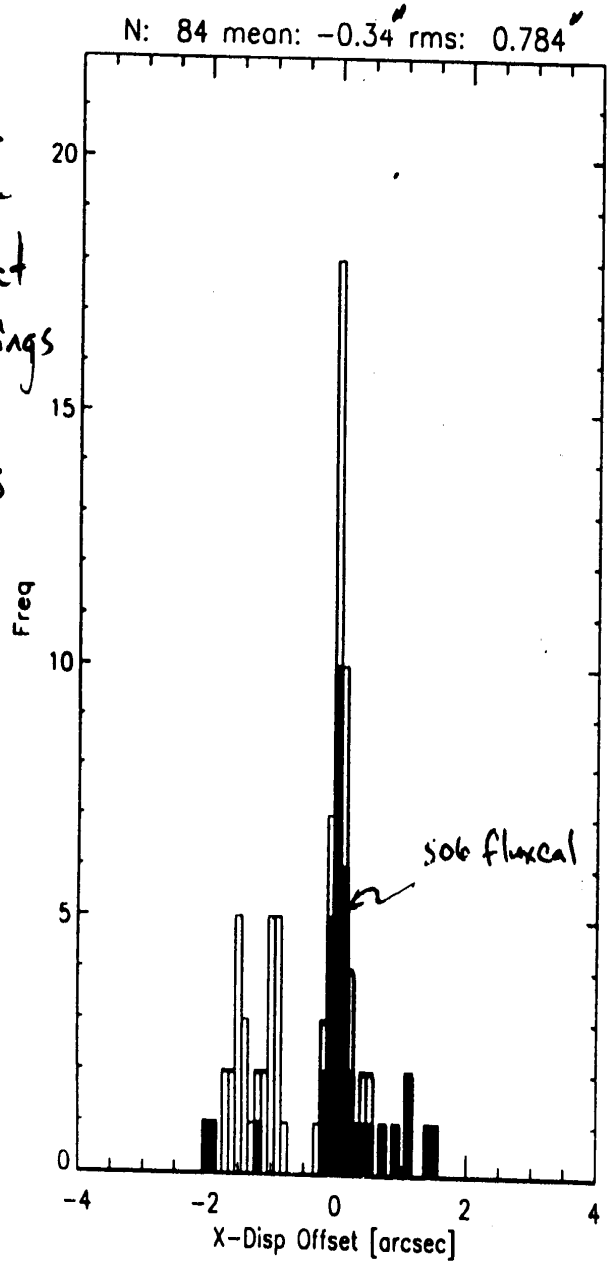
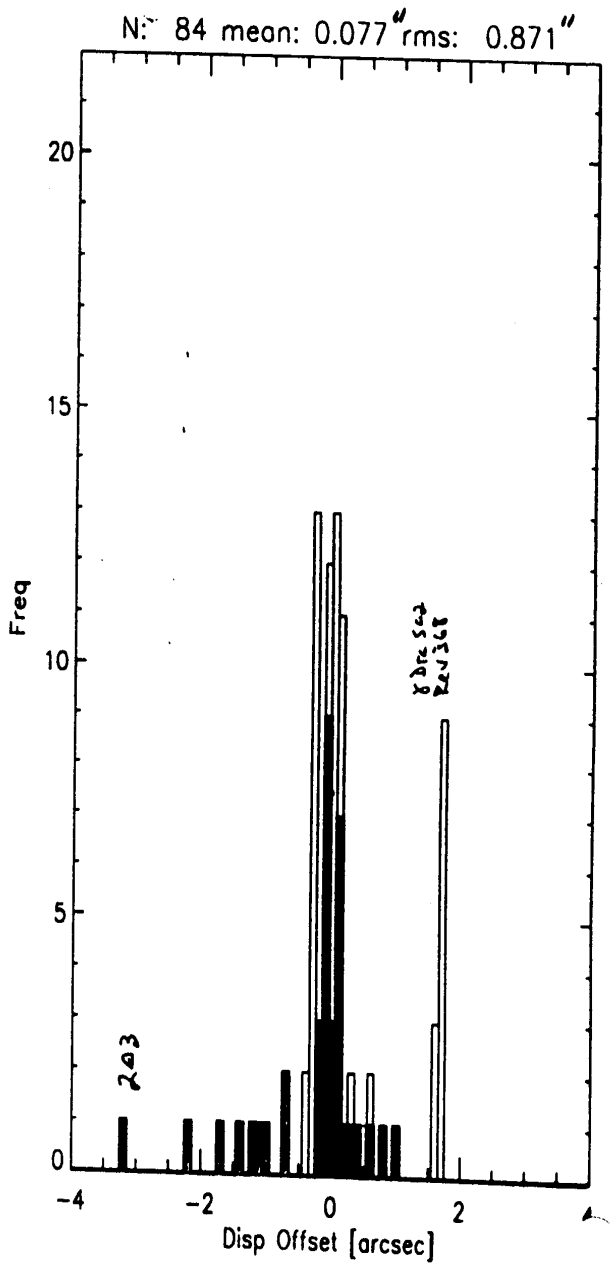


Figure 3: PV Beam profiles in selected AOT bands, normalized to peak response and shifted by factor 3.

Schaeidt et al 1995, A&A

γ Dra calib. observns – little impact of mispointings (≤1") on calibrations





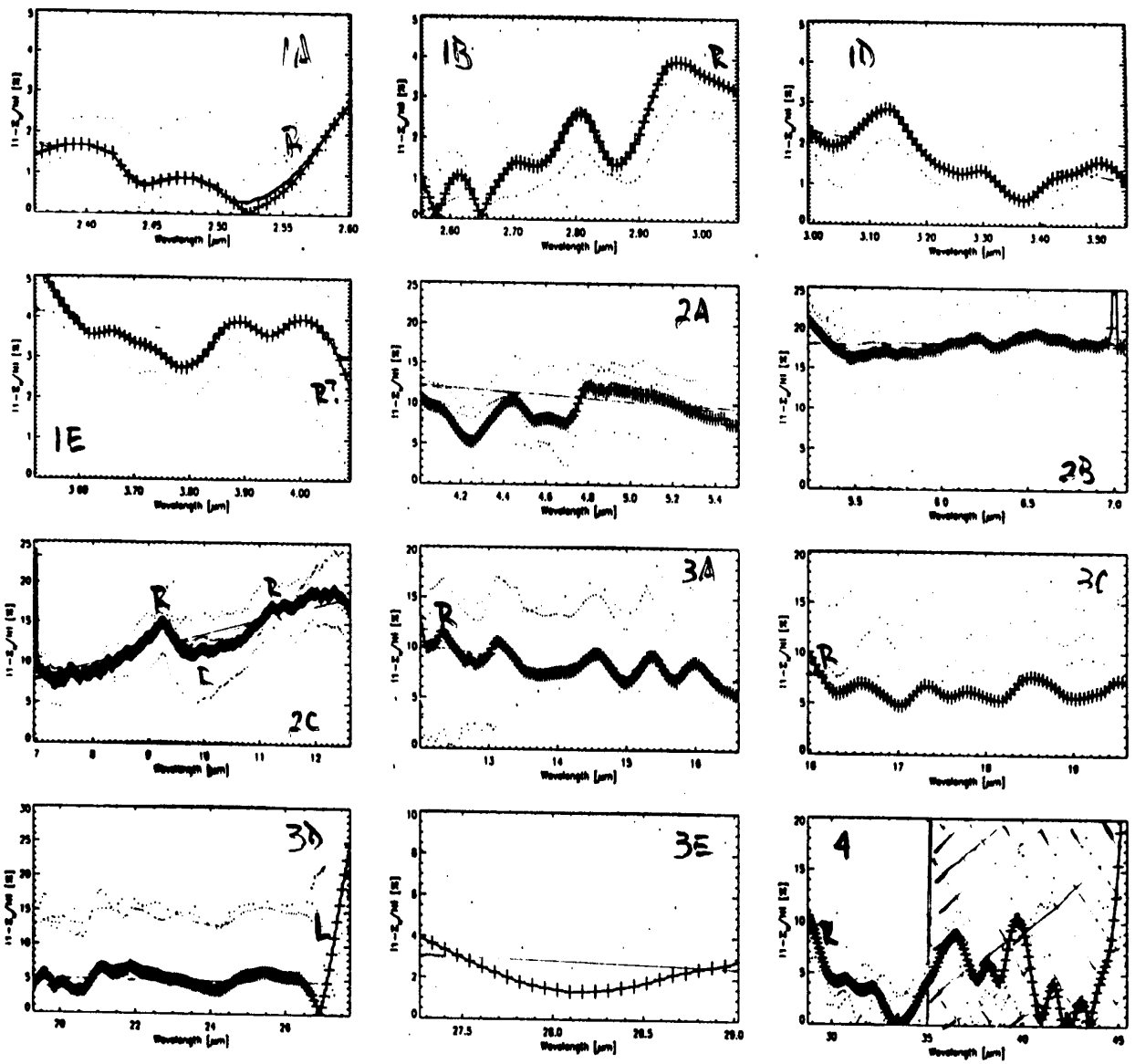
Photometric Calibration Uncertainties

Contributing systemic factors:

- Dark currents
  (memory, hysteresis, and dark current characterization);
- Pointing (sampled from calibrators and science database);
- Reference spectral templates, photometry.

RMS variation *from reference SEDs* (not strict absolute photometric uncertainties vs λ)...

$|1 - \frac{1}{(N-1)} \Sigma_N F_\lambda(SWS)/F_\lambda(\mathrm{ref})|$ at $\lambda/\Delta\lambda \sim 50$:



Systematic differences (?) between K III observed and reference

↑

Mainly M. Cohen Composites

R = suspect RSRF

L = leakage

$\lambda/\Delta\lambda \approx 50$

These are not absolute uncertainties