BOL | QMW / M | 0024·10

FIRST BOLOMETER INSTRUMENT MEETING
MARSEILLE 22, 23 SEPTEMBER 1997
DRAFT AGENDA

Monday 22 September

1.	**FIRST status and schedule**	**M Griffin**	**14.00**
2.	**Photometer optical design and layout**	**E Atad**	**14.30**
3.	**Grating optical design and layout (single grating option only)**	**K Dohlen**	**15.30**
4.	**Smaller meeting of group leaders to discuss consortium make-up and management structure (splinters in parallel as necessary)**		**16.30**

Tuesday 23 September

5.	**Summary of base-line optical for PHOT and SPEC**	**B Swinyard**	**09.00**
6.	**Beam clipping and stray light**	**M Caldwell**	**09.30**
7.	**Cooler options**		
	- Detector requirements and technical constraints	**M Griffin**	**10.00**
	- Dilution system	**A Benoit**	
	- He-3 sorption cooler	**L Duband**	
	- Summary	**M Griffin**	
3.	**FTS and grating options**		
	- Scientific/technical constraints	**M Griffin**	**11.30**
	- Results of study to date	**B Swinyard**	**12.00**
	Lunch		**12.30**
	- FTS design options and mechanism	**P Ade**	**14.00**
	- FTS optical design	**K Dohlen**	**14.30**
	- Summary	**B Swinyard**	**15.00**
4.	**Consortium make-up and management structure**	**M Griffin**	**15.30**
5.	**Plans/meeting arrangements for preparation**	**M Griffin**	**16.00**
6.	**Actions**	K King	**17.00**
	Meeting ends		**17.30**

Wednesday 24 September (am): **Available for splinter meetings**

FIRST STATUS

1. Merger industrial study is continuing with parallel study internally within ESA) of an independent PLANCK mission
2. AO for FIRST and PLANCK instruments will be issued 30 September
3. Briefing meeting for questions to ESA Nov. 27
4. Response due ~ Feb. 15
5. NASA have agreed to provide 3.5-m telescope plus other contributions (e.g., communications antenna)

   Total ~ $75-80M (inc. ~$20-25M for instruments).

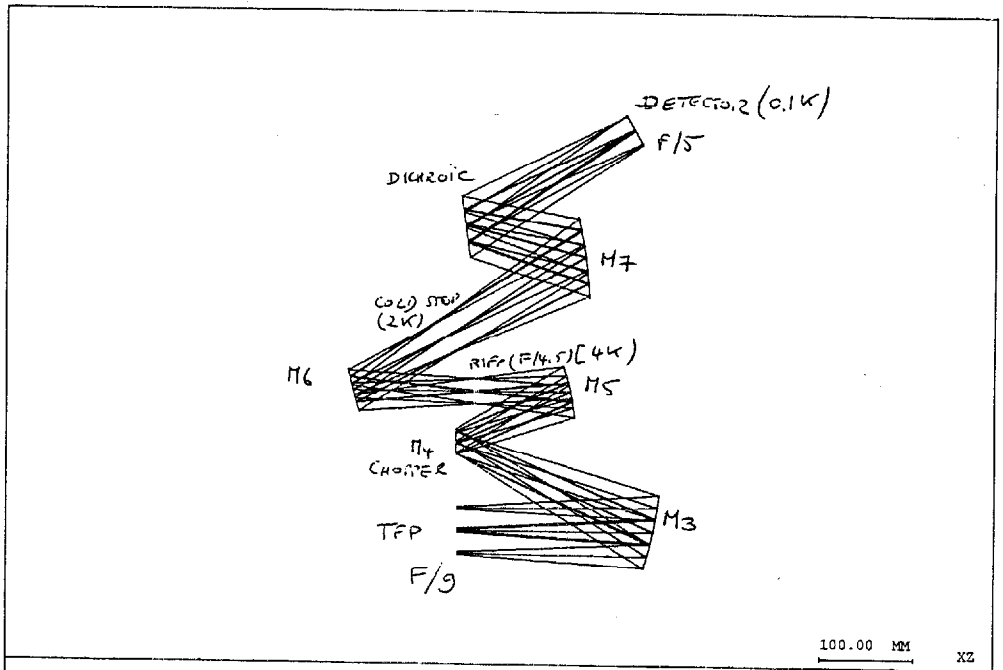
Preliminary Optical Design of BOL (version 2)
Eli Atad , ROE , 23 September 1997

Photometer / Imager (designed with 3.5 m; F/9 FIRST)

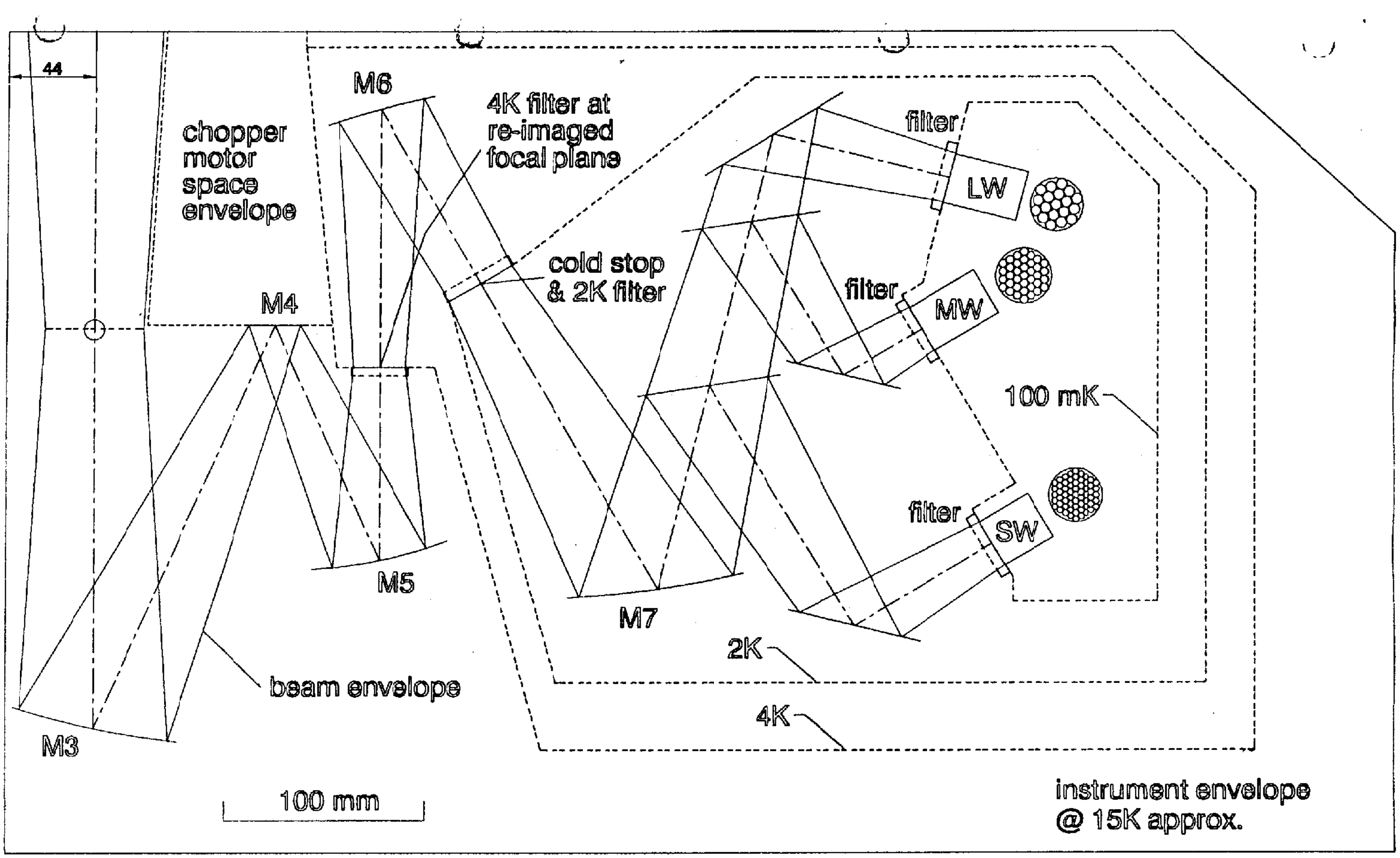
- Working wavelengths: 200-600 microns
- Fnumber: F/5
- Field of View: 5 arcmin (the previous fov was too big to accommodate the 3 dichroics and the detector size (25 mm)
- Chopper in the instrument and placed at the image of FIRST secondary mirror which is the stop of the telescope.
- Has to fit with the spectrometer in the 700*300*300 mm space enveloppe.
- A physical cold stop at 2K to reduce background radiation.
- The photometer will share the same foreoptics as the spectrometer (one chopper only, weight) ,providing an f/4.5 beam for the eventual slit .
- 3 arrays of detectors optimized for 3 separate wavelengths: 250, 350,480 microns .
- No Filter wheel .

OPTICAL LAYOUT OF BOLPHOT :

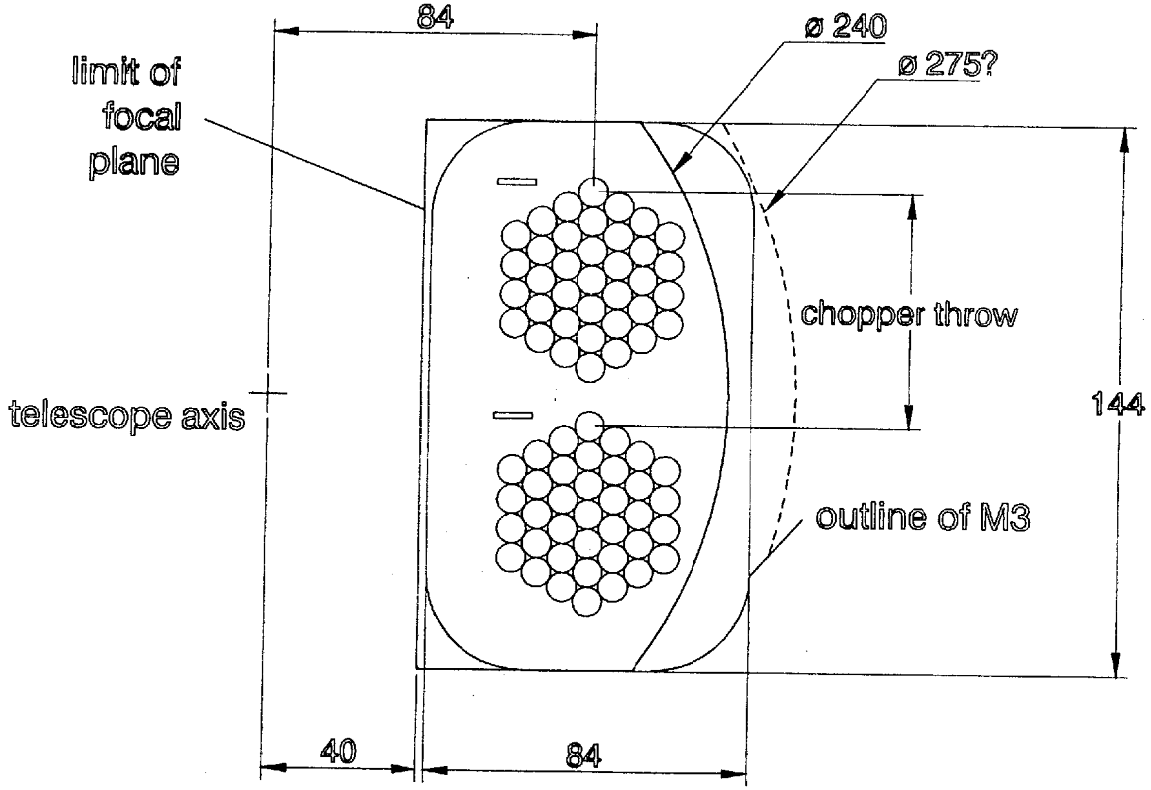
14:44:18



BOL PHOT F/5; 3.5 m telescope;Fslit/4.5 Scale: 0.25 19-Sep-97



BOL photometer 20.09.97
f/5 final beam size
dichroic angle - 22.5 degrees



BOL instrument
spectrometer slit and
photometer detector array
mapped to the telescope focal plane

ERROR: timeout
OFFENDING COMMAND: timeout

STACK:

Photometer/Imager Optical Data:

Component	Radius of Curv (mm)	Thickness (mm)	y- Tilt (degrees)	CA Diameter (mm)
telescope FP f/9 (20K) (6.548"/mm)	Plano	200		50.0
M3 (sphere)	400.00	220.88	12.0	80.0
M4 (chopper)	Plano	128.83	24.0	26.0
M5 (toroid)	199.78 215.53	96.40	12.0	55.0
Cold reimaged Focal plane f/4.5 (4K)	Plano	129.18		27.0
M6 (sphere)	486.66	100.34	15.0	43.0
cold stop (2K)	Plano	177.00		40.0
M7 (toroid)	375.53 446.35	127.00	22.0	80.0
M8 (dichroic)	Plano	198.00	22.0	65.0
Detector/f/5				25.0
(11.79"/mm)				

IMAGE QUALITY

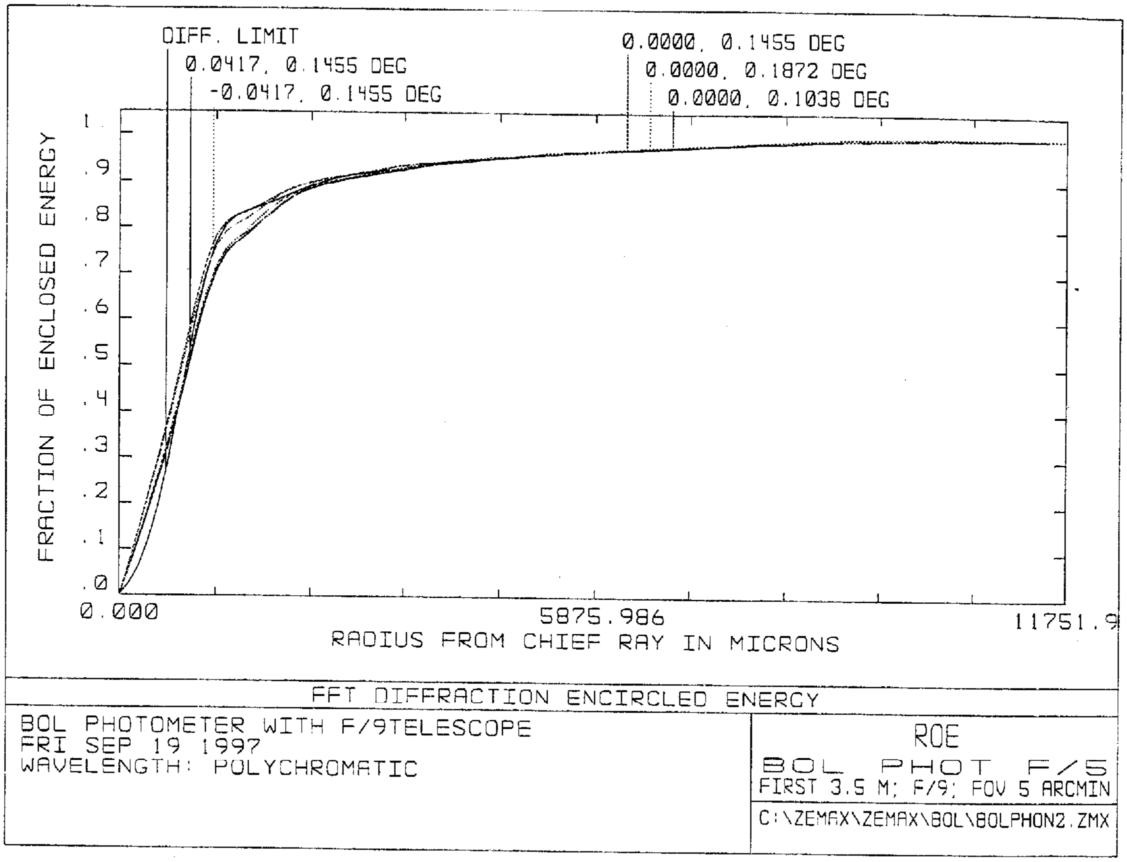
Encircled Energy Diameters (mm) and Strehl ratios:

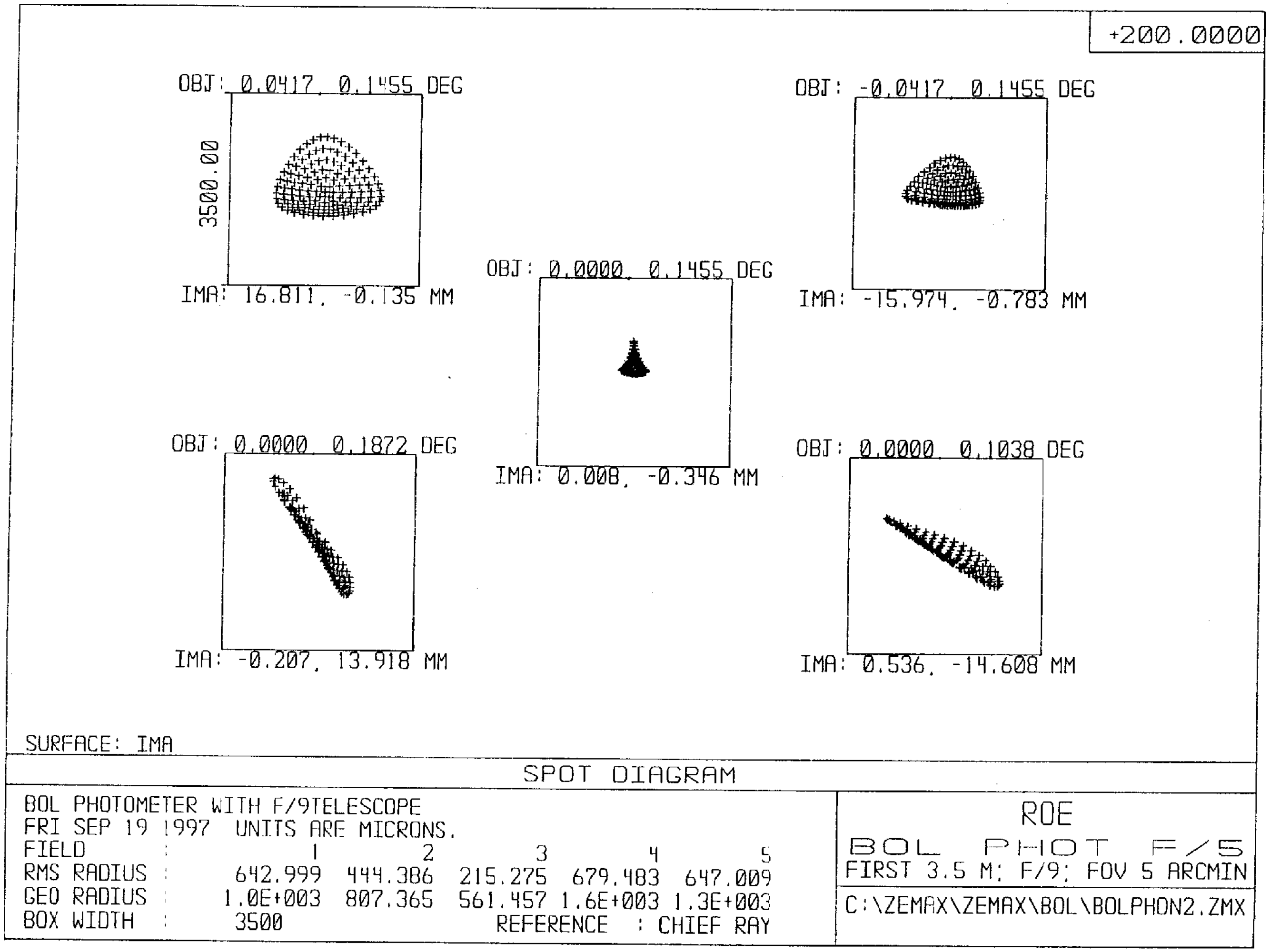
Wavelength (µm)	250	350	480
Airy disk (80%) (mm)	2.5	3.5	4.8
Geometrical spots (mm)			
80% on-axis	0.44	0.44	0.44
off-axis	1.60	1.60	1.60
Strehl ratios			
on-axis	0.99	1.0	1.0
off-axis	0.90	0.95	0.97

THROUGHPUT : 0.89 (without filters)

(assuming 0.98 reflectivity per mirror)

ENCIRCLED ENERGY (Diff.Limit at 200 microns)





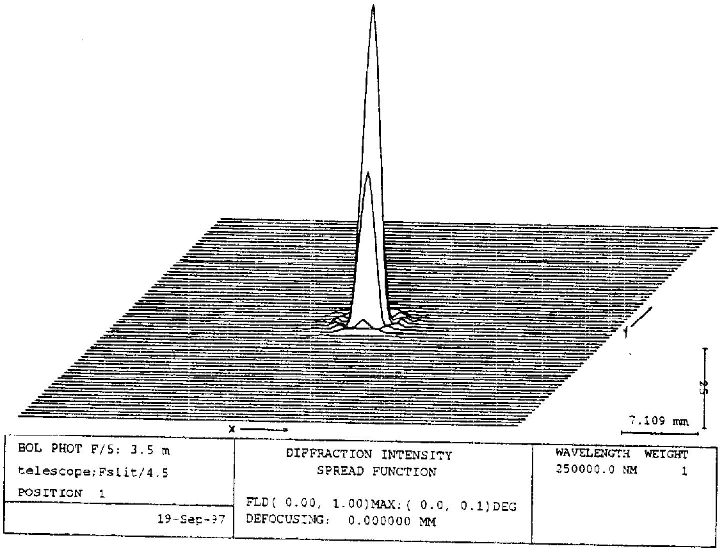
SPOT DIAGRAM

```
BOL PHOTOMETER WITH F/9TELESCOPE
FRI SEP 19 1997  UNITS ARE MICRONS.
FIELD       :        1        2        3        4        5
RMS RADIUS  :    642.999  444.386  215.275  679.483  647.009
GEO RADIUS  :    1.0E+003 807.365  561.457 1.6E+003 1.3E+003
BOX WIDTH   :     3500              REFERENCE  : CHIEF RAY
```

ROE
BOL PHOT F/5
FIRST 3.5 M; F/9; FOV 5 ARCMIN
C:\ZEMAX\ZEMAX\BOL\BOLPHON2.ZMX

PSF BOLPHOT

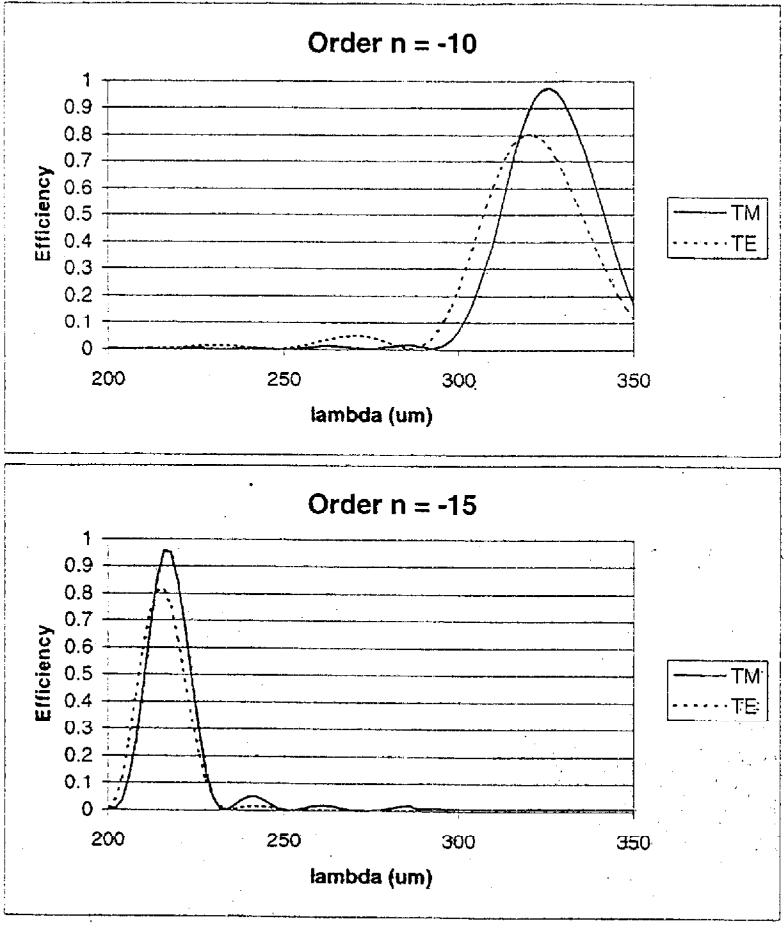
On-axis and Off-axis

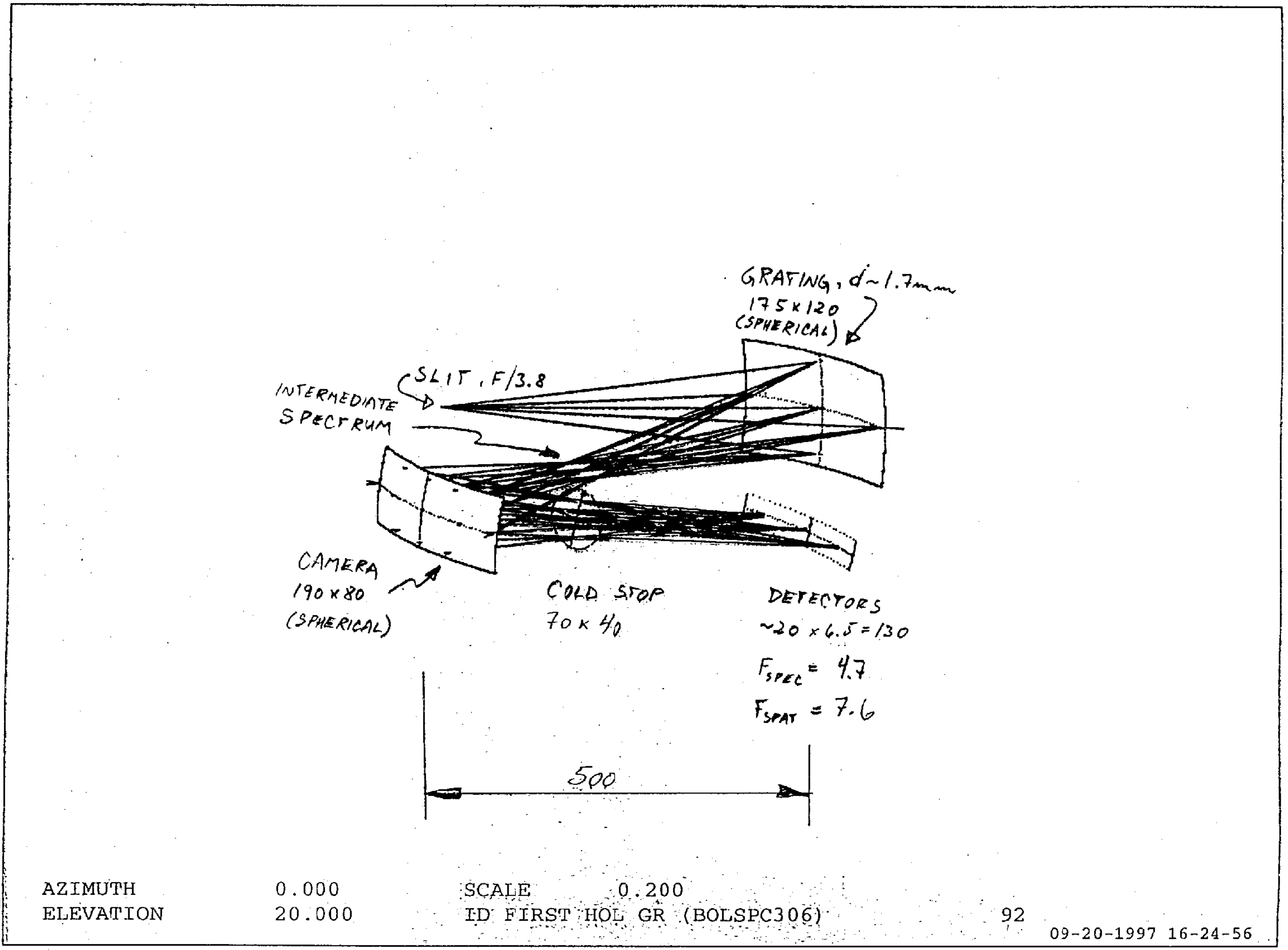


SPOT DIAGRAMS:

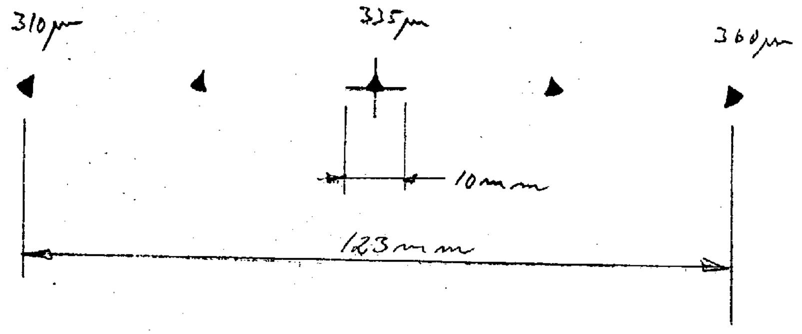
Polarizated efficiency , d = 2.531 mm, blaze = 40.08 deg, alpha = 45 deg

(M. Neviere, Labo d'Optique Electromagnetique, Marseille, 190997




GRATING, d~1.7mm
175x120
(SPHERICAL)
SLIT, F/3.8
INTERMEDIATE SPECTRUM
CAMERA
190x80
(SPHERICAL)
COLD STOP
70x40
DETECTORS
~20 x 6.5 = 130
F_{SPEC} = 4.7
F_{SPAT} = 7.6
500
AZIMUTH 0.000
ELEVATION 20.000
SCALE 0.200
ID FIRST HOL GR (BOLSPC306)
92
09-20-1997 16-24-56

THROUGH-FOCUS SPOT DIAGRAM



0.000

FRACTIONAL
FIELD

0.00000
DEFOCUS

25.4000 MM
WAVELENGTH
SEMI-FIELD = 1.0000 MM

ID FIRST HOL GR (BOLSPC306)
335.00000 310.00000 360.00000 322.50000 347.50000
SEMI-APERTURE = 50.0000 MM

92

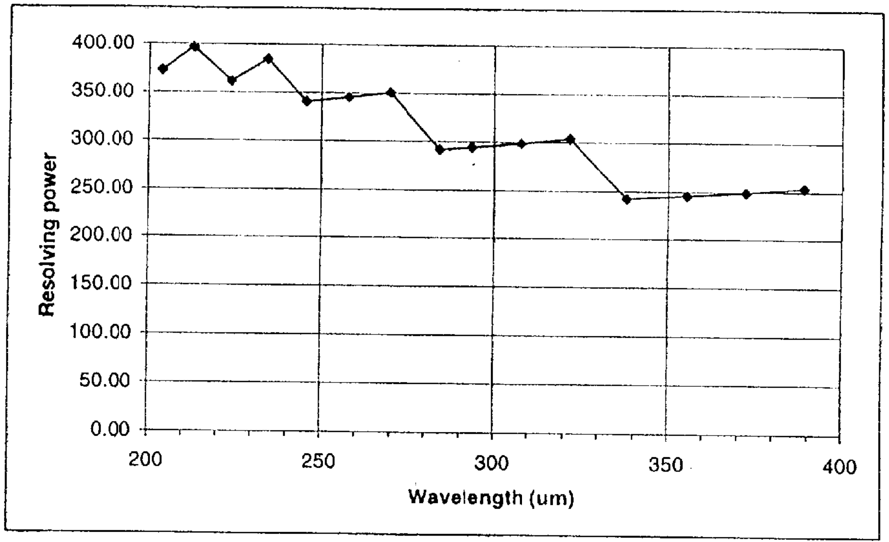
09-20-1997 16-45-53

Summary of detector distribution and estimated resolving power

Calculation of resolving power uses estimated spot size for given grating size (BOLSP305.MAC)

KD, LOOM 20/9/97 17:20

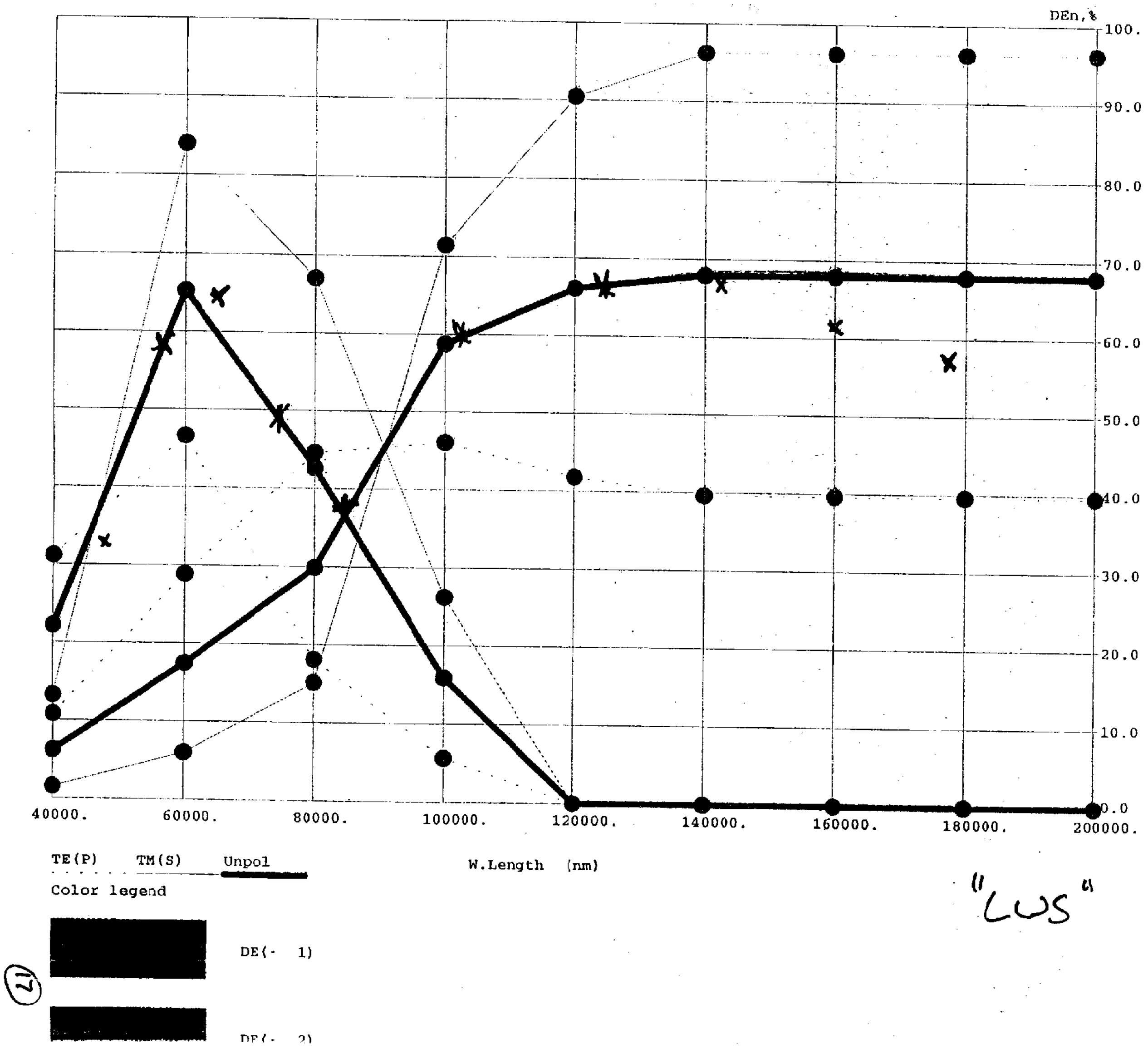
Slit angle	alpha	53	deg
Focal length	fCam	760	mm
Det. sep.	dDet	6.6	mm
Ang. det. sep	dbeta	0.50	deg
Dead area	dDead	2.00	mm
Max horn wdth	dHornMax	4.60	mm
Ang max horn	dbetaMax	0.35	deg
No of detectors	Ndet	19	no unit
Central det. angle	beta0	16	deg
Central detector	iD0	10	no unit
Grating constant	d	1.693	mm
Scan range (+-)	dNdet	3	no unit
Lowest order	n0	5	no unit
Central wavl	lam0	363.75	um
Longest wavl	lamL	398.46	um
Shortest wavl	lamS	327.94	um
Grating width	DgrSpec	161	mm
Spot FWHM	dSpot	2.30	mm
Angular spot	dbetaSpot	0.17	deg
Fnum at pick-off	Fslit	3.80	no unit
Airy disk factor	AiryFact	2	no unit



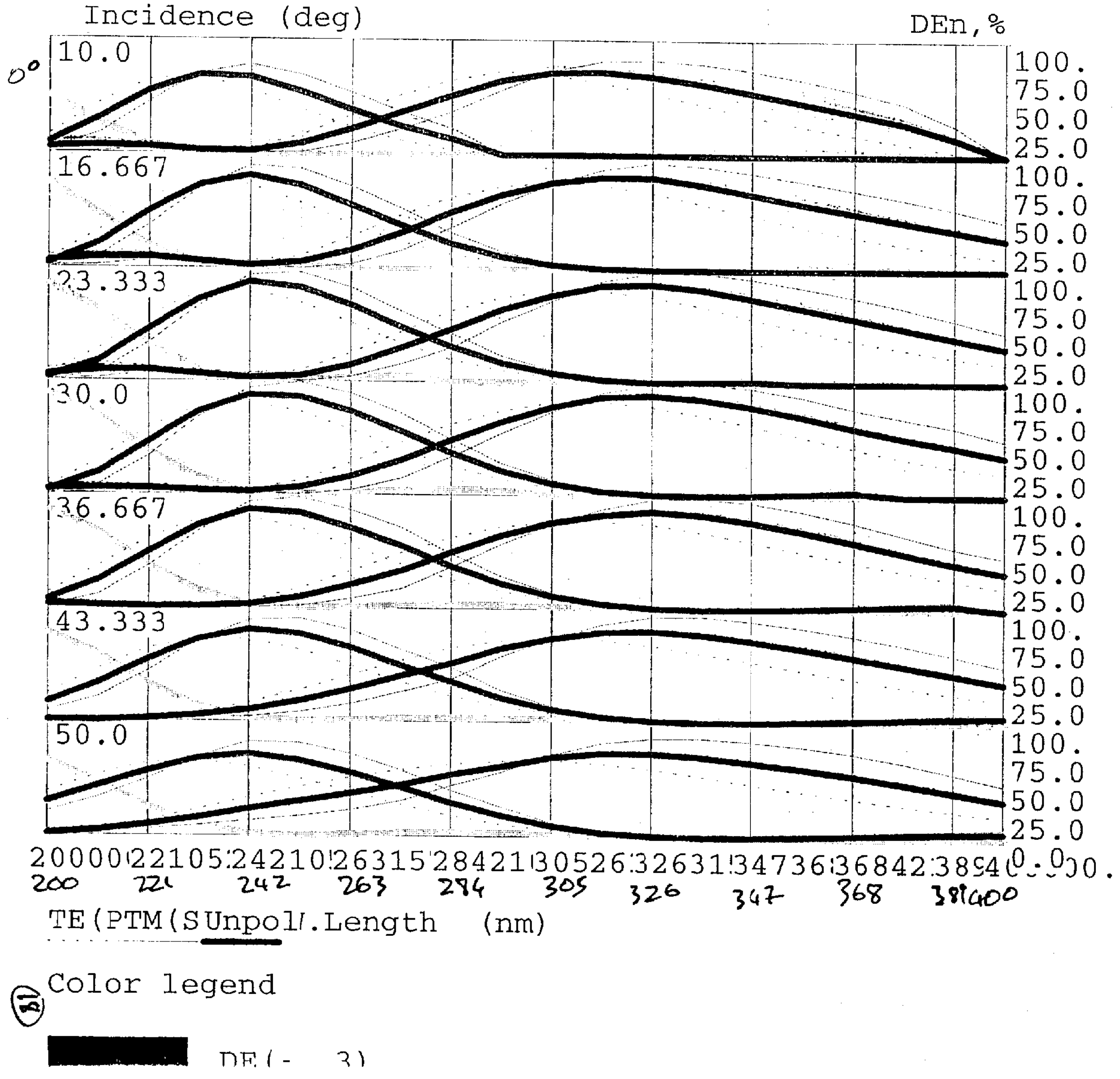
Range index iR	Order n	Det. index iD	Max angle betaMx	Centr. angle betaC	Min angle betaMn	Max lam lamMx	Central lam lamC	Min lam lamMn	Airy disk dAirySpec	Horn wdth dbetaSpecL	Res. Pow. Ropt
1	5	19	21.97	20.48	18.99	397.10	388.88	380.57	0.28	0.28	253.78
2	5	13	18.99	17.49	16.00	380.57	372.20	363.75	0.26	0.26	249.27
3	5	7	16.00	14.51	13.01	363.75	355.24	346.67	0.25	0.25	245.57
4	5	1	13.01	11.52	10.03	346.67	338.05	329.39	0.24	0.24	242.63
5	6	18	21.47	19.98	18.49	328.64	321.76	314.82	0.23	0.23	303.56
6	6	12	18.49	17.00	15.50	314.82	307.82	300.77	0.22	0.22	298.32
7	6	6	15.50	14.01	12.52	300.77	293.66	286.50	0.21	0.21	294.04
8	6	2	13.51	12.02	10.53	291.28	284.11	276.90	0.20	0.20	291.69
9	7	15	19.98	18.49	17.00	275.80	269.85	263.85	0.19	0.19	350.95
10	7	9	17.00	15.50	14.01	263.85	257.80	251.71	0.18	0.18	345.41
11	7	3	14.01	12.52	11.02	251.71	245.57	239.41	0.17	0.17	340.94
12	8	14	19.48	17.99	16.50	239.59	234.37	229.11	0.17	0.17	384.76
13	8	8	16.50	15.00	13.51	229.11	223.80	218.46	0.16	0.17	361.78
14	9	17	20.98	19.48	17.99	217.57	212.97	208.33	0.15	0.17	396.83
15	9	11	17.99	16.50	15.00	208.33	203.65	198.93	0.14	0.17	373.09

SPEC-BOL CONCLUSIONS:

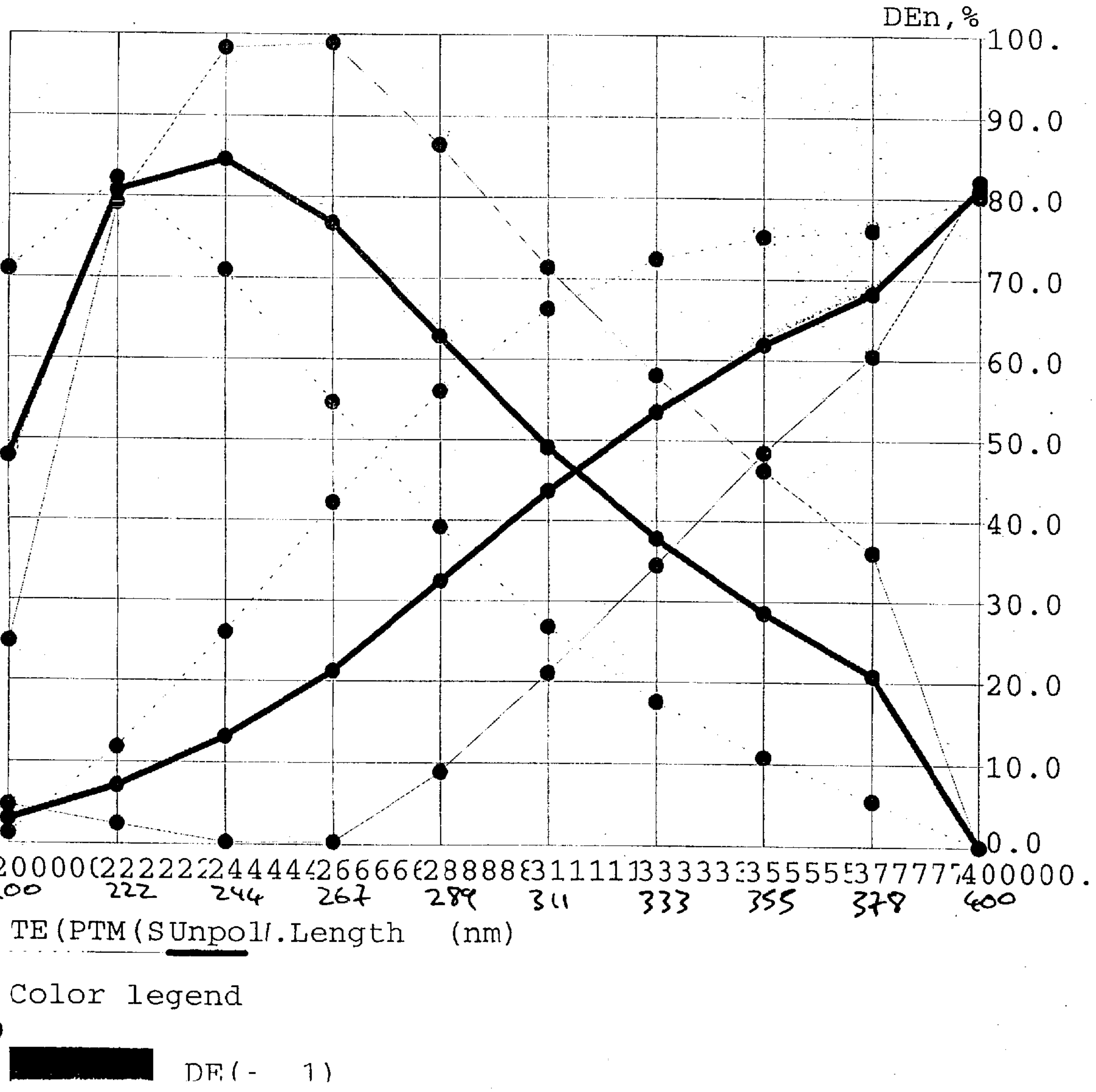
- **Compact and simple design**
  - 2 spherical surfaces + pick-off mirror (probably toroidal)
- **Improved grating design**
  - Stigmatic intermediate spectrum
  - Camera mirror is spherical: no more heavily deformed surface
- **Tolerant**
  - ±1° grating tilt tolerable
  - Scanning grating
  - Stationary cold stop
- **Accessible cold stop and intermediate spectrum**
- **Detectors on a circle, concentric with cold-stop**
  - Effectively telecentric final image
- **Only hard point: fabrication of grating, may need 5-axis milling**
  - Hyperfine is confident
  - Separate stigmatic testing of grating simplifies procedure


DEn,%
100.
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
40000.
60000.
80000.
100000.
120000.
140000.
160000.
180000.
200000.
W.Length (nm)
TE(P)
TM(S)
Unpol
Color legend
DE(- 1)
DE(- 2)

"LWS"



1MM groove
-3, -4, -5 ORDERS.



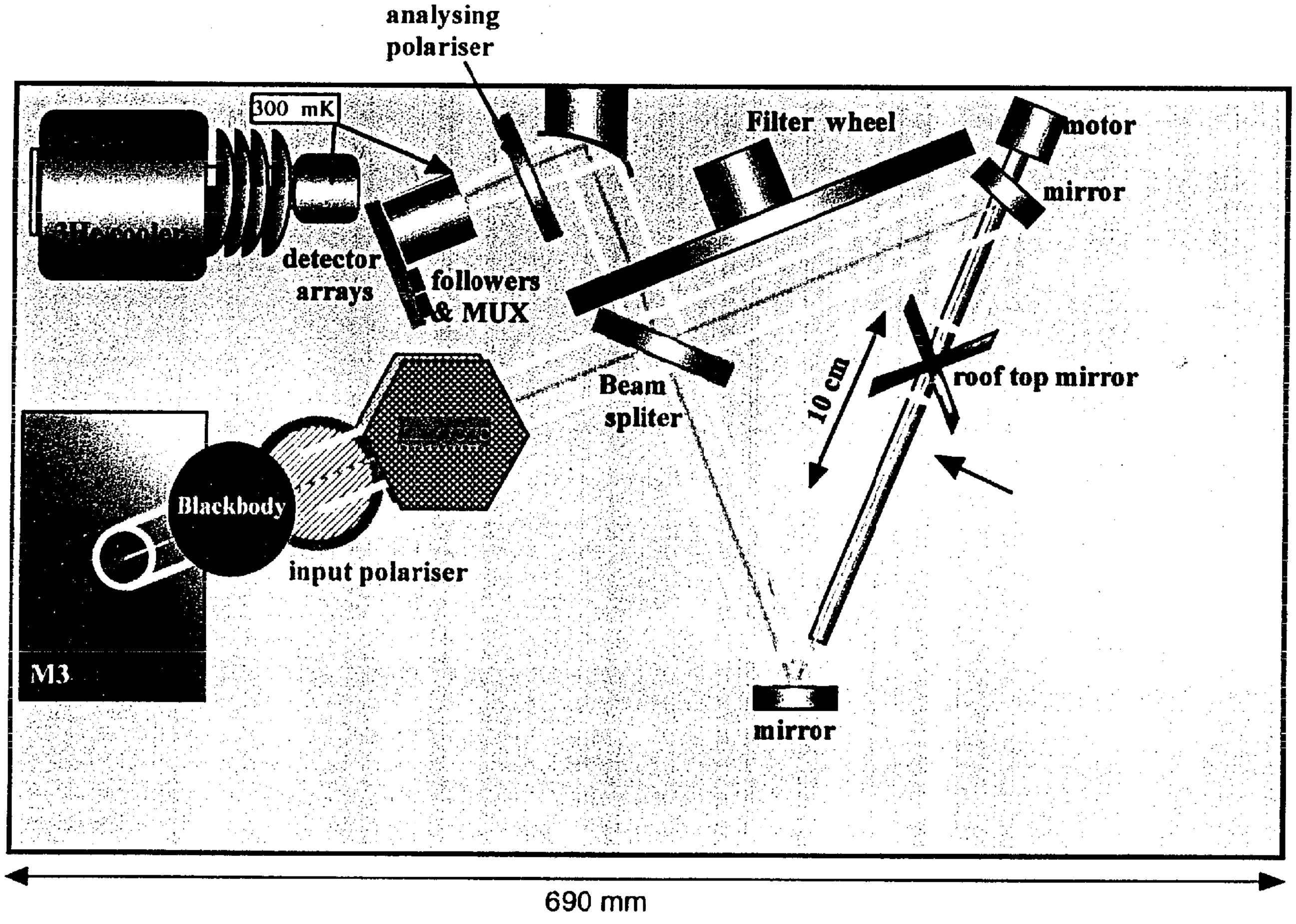
0.5mm groove
-1, -2 ORDERS.

AN IMAGING FOURIER TRANSFORM SPECTROMETER FOR SUB-MILLIMETER WAVES ANALYSIS

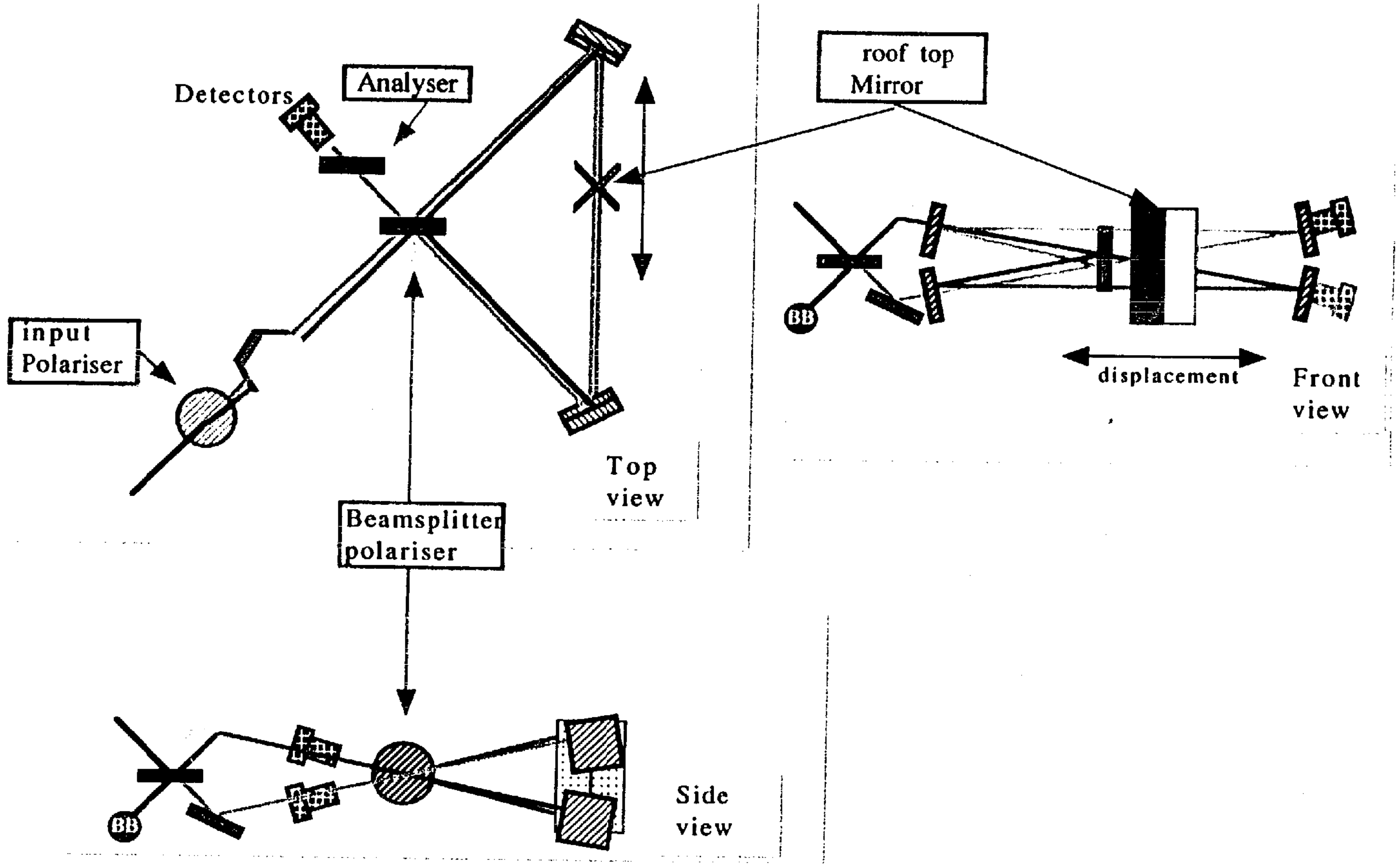
L. Rodriguez

CEA/DAPNIA/SAp
France

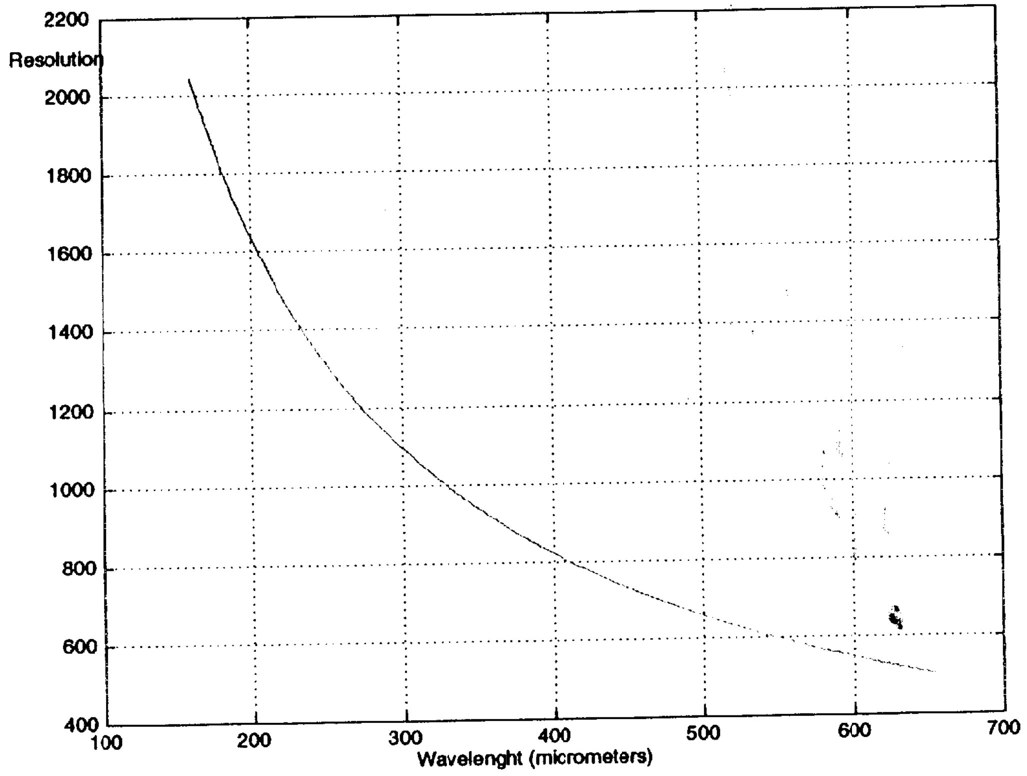
INTERFEROMETER BULK



A TWO BEAM SHARED SPECTROMETER

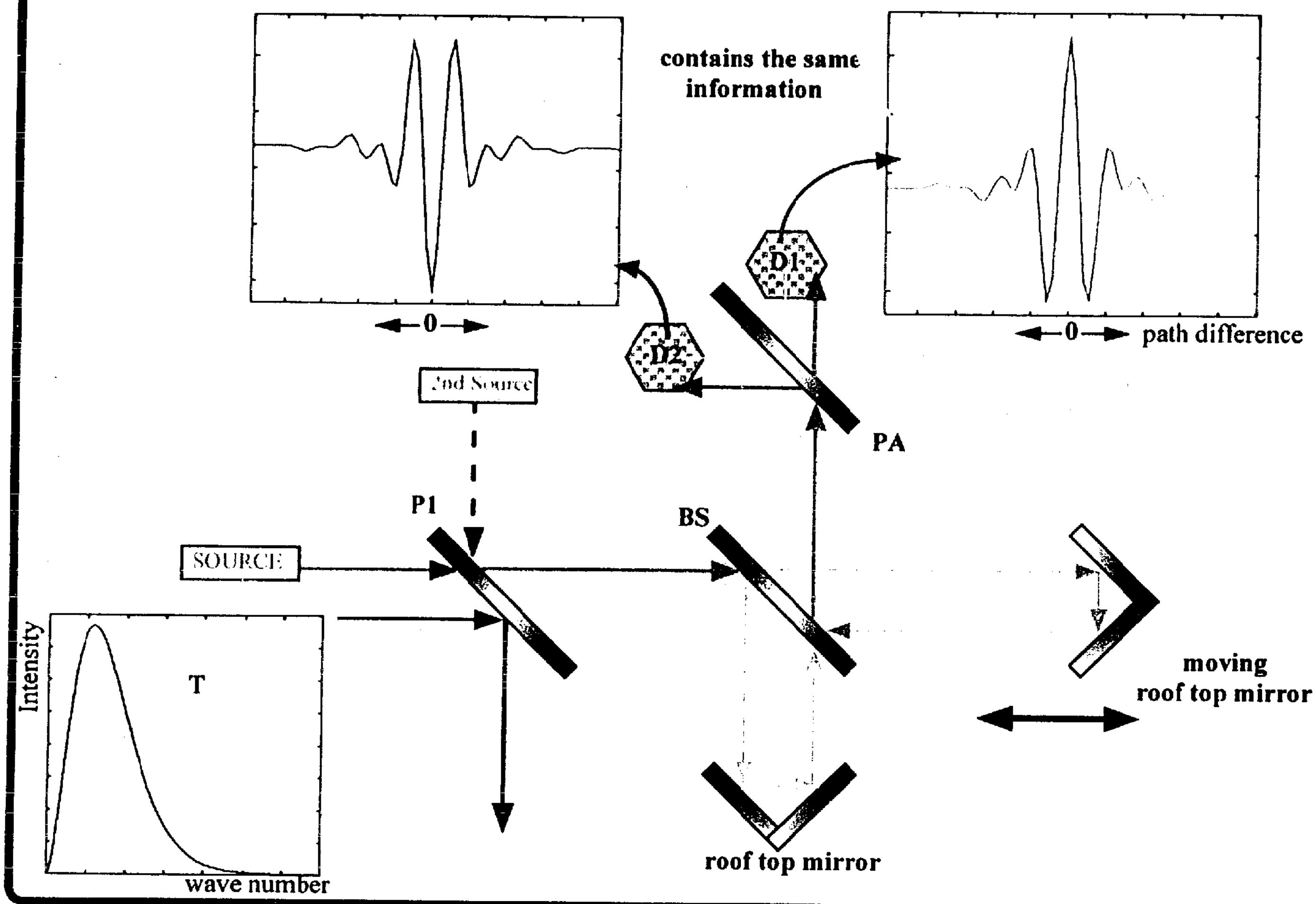


SPECTRAL RESOLUTION

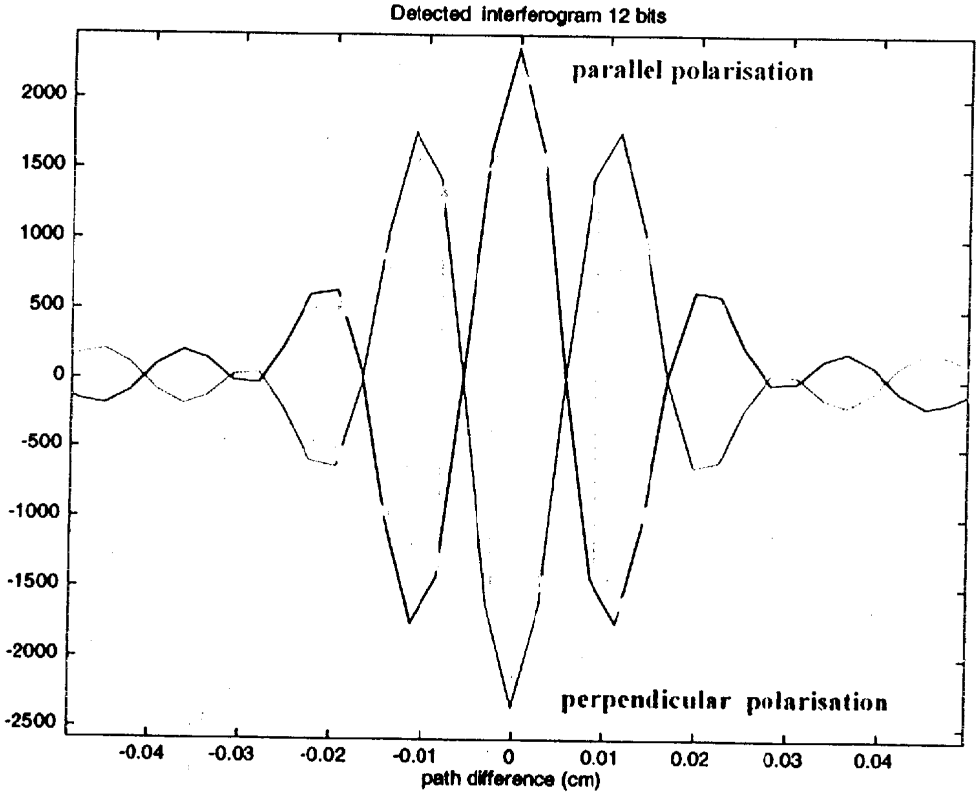


➡ for 1050 steps of 80 micron. Single sided interferogram with 50 step phase correction double moving path

THE MARTIN-PUPLETT INTERFEROMETER



ACQUISITION STRATEGY



Background signals in PHOT-BOL

(Tony Richards RAL/BOL/N0007.1)

- Direct contribution:- emission from mirrors.
- Diffraction contribution:- Emission from telescope tube,via mirror edge.

Beam propagation analysis (Martin Caldwell).

- Mirror oversizes to avoid beam clipping
- Instrument FOV response with/without clipping (N0015.01)

PHOT-BOL background signals.

Direct emission from mirrors.

1. Dominated by telescope mirrors:

Table 1. Fractions of integrated power from each component, in each waveband

Component	T° K	ε	Fraction of Filtered Power per pixel, band 1	Fraction of Filtered Power per pixel, band 2	Fraction of Filtered Power per pixel, band 3
M1	80	0.01	0.48225	0.46584	0.4481
M2	80	0.01	0.48711	0.47054	0.45262
M3	15	0.01	0.01011	0.02099	0.03272
M4	15	0.01	0.01021	0.0212	0.03305
M5	15	0.01	0.01032	0.02141	0.03338
M6	4	0.01	0.0	0.0	0.0
M7	2	0.01	0.0	0.0	0.0
M8	2	0.01	0.0	0.0	0.0

2. Nearly equals permitted level in bands 1 & 2, exceeds it in band 3 :

Table 2. Maximum permitted background power/pixel compared with estimates (table 5)

waveband	λmin, microns	λmax, microns	Max. Permitted Power WATTS	Estimated direct background from all mirrors, WATTS
1	200	300	22.0*10^-12	17.817*10^-12
2	300	400	10.0*10^-12	8.435*10^-12
3	400	650	4.0*10^-12	10.374*10^-12

Concern: Assumes emissivity of spider is also 0.01.

PHOT-BOL background signals.

Telescope tube emission, diffracted into FOV.

- Tube between FIRST primary mirror and BOL.

  Emissivity= 0.15, T=80K

- Analysis based on analytic model:

  1. Diffraction at single aperture (M3 used).
  2. Centre detector only.
  3. Rotational symmetry.
  4. Approx. baffle angles (from centre detector).
  5. Incoherent detector (top-hat beam, worst case).

- Result: Level at centre of FOV is 1/5 of budget.

Beam propagation model.

Purpose.

1. To show potential 'clipping' of beams, as an aid to design & mirror sizing.

   PHOT-BOL : RAL/BOL/N0006.1.

   Updated for:

   - Detector modelled both as bare detector (top-hat beam) and Winston cone (gaussian beam).
   - latest design (except BOL still at centre of telescope FOV).

   FIRST/BOL interface:- RAL/BOL/N0013.

2. To compute FOV with clipping included.

   RAL/BOL/N0015.

29

Beam propagation analysis.

CLRC

Model of diffractive beam propagation.

Propagates detector sensitivity function outwards through system on to sky.
(mm-wave method).

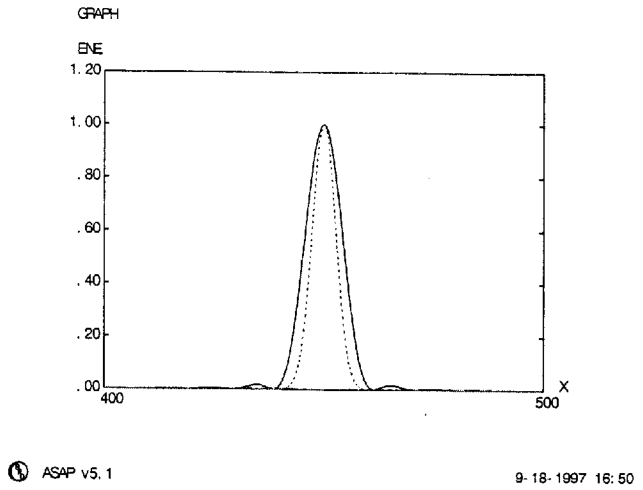
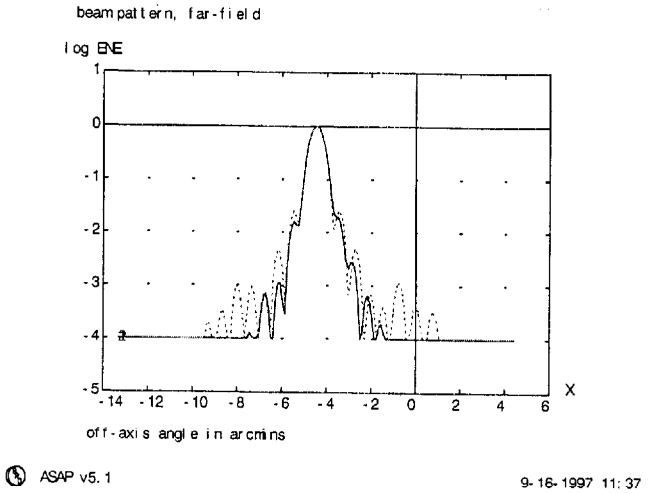


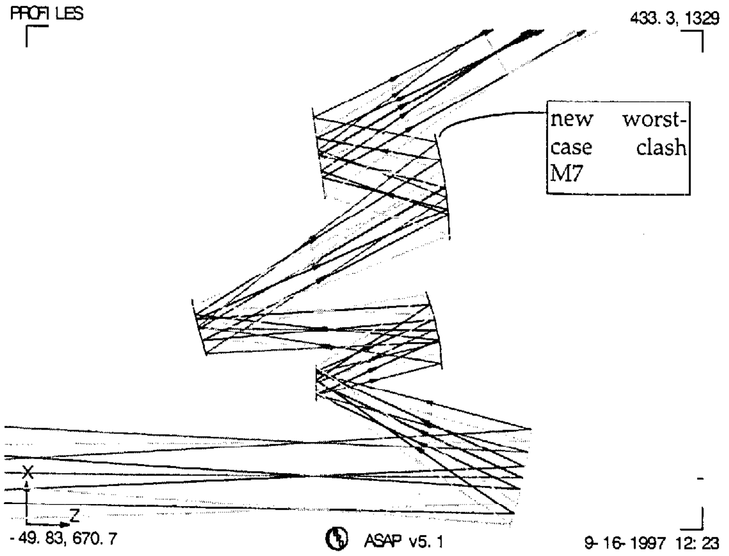
Fig.2 Beam patterns at detector plane, for gaussian (dotted line, waist=$(2/\pi)F\lambda$, $1/e^2$ intensity clipping) and top-hat (solid line, 1st min=$1.22F\lambda$), λ=0.64mm.

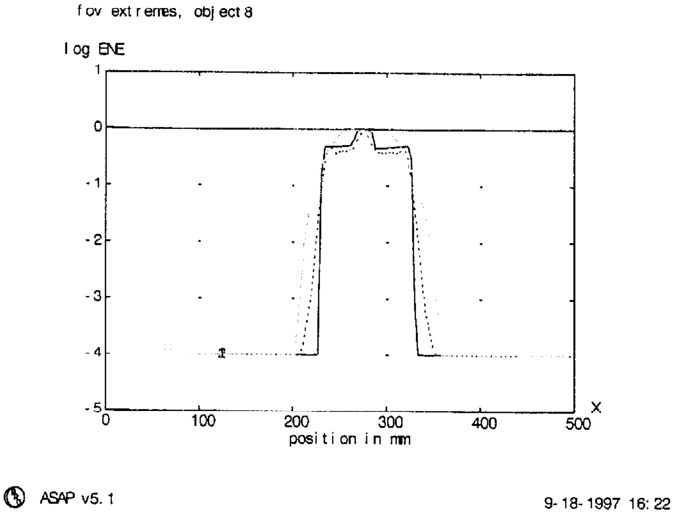


Instrument response on sky: point source transmittance (PST).

Beam propagation analysis.

Latest PHOT-BOL design.





Pattern on mirror M7. Generally an oversize 20 - 30 % suffices for -30dB taper

Beam propagation analysis.

Field-of-view model.

Features.

- Finite detector size not yet included. Should be, since incoherent detector.
- Detector response invariant with wavelength. (not so for coherent detector).
- Field position: outermost detector in array, but not true off-axis design.
- Wavelength: 640µm. (Worst-case for diffraction).

Unclipped case

- Assumes beam pattern is not clipped at any component.
- Assumes PST does not change over off-axis-angle range of interest.

Clipped case.

- Beam pattern is clipped by chosen component(s) (currently PM cut-out).
- PST varies with beam angle, therefore propagation step is repeated for all angles.

Main limitation:

Describes clipping edges only to spatial resolution >λ (0.64mm here)

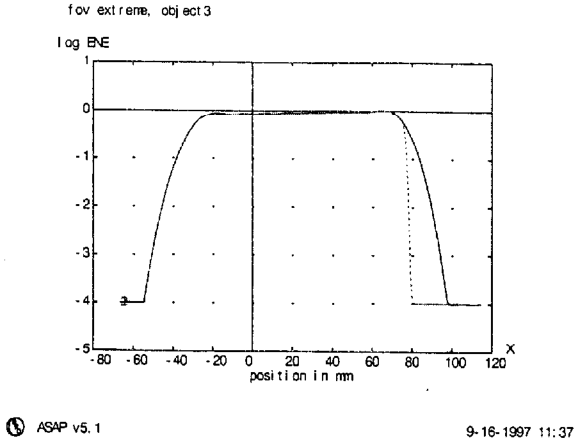
32

Beam propagation analysis.

Effect of clipping on FOV.

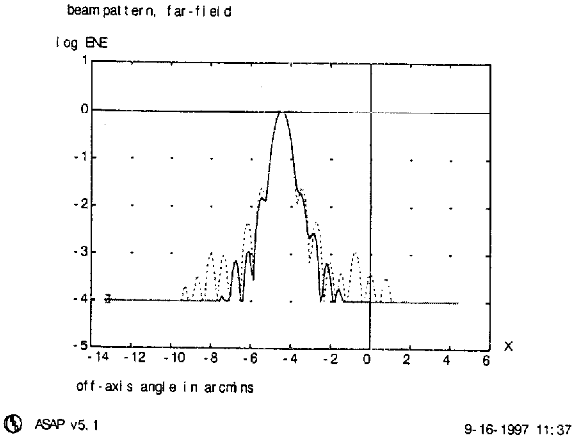
- clipping ONLY at M1 cut-out, assuming this is sized for the geometric beam.

1. Beam pattern at M1 (top-hat), with & without clip:



2.4 % of the beam pattern views the back of M1 (at 80K).
⇒ Background ≈ 100% of budget if ε=1.

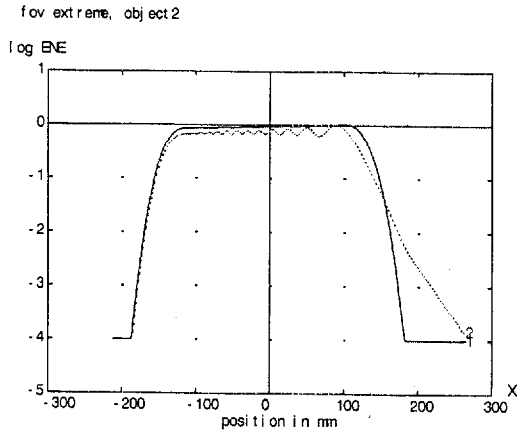
2. Effect on PST response.



must compare with required instrument dynamic range

Other beam patterns from clipping at M1 cut-out (solid line=unclipped, dashed = clipped)

at M2 :



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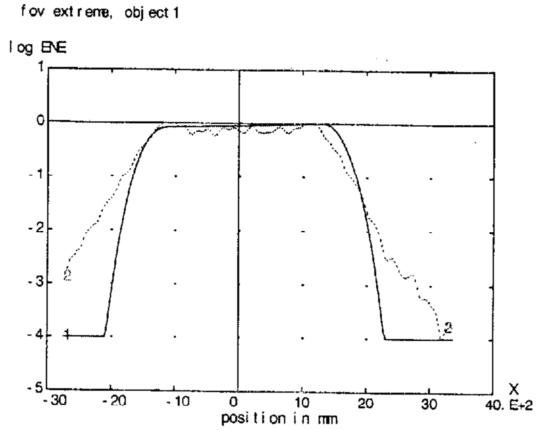
at M1 :



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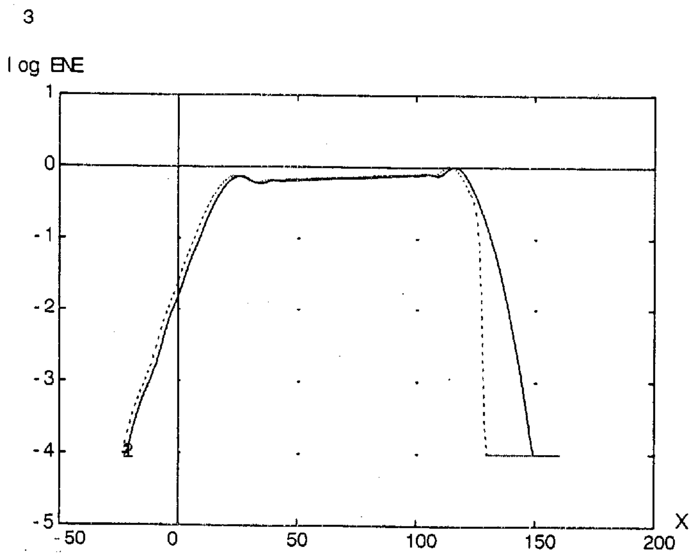
Shows that additional clipping will then arise at these mirrors.

Beam propagation analysis.

Actual off-axis geometry.

- Assuming BOL FOV is 80mm off-axis at telescope focal plane.
- for beam of outermost detector in array.



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Assumes M1 cut-out has radius = 127 mm.

Telescope apertures & obscuration factor are needed.

Conclusions.

- Beam clipping can be made negligible in PHOT-BOL by oversizing mirrors.

    (oversizes ~ 30% in aperture for -30dB edge tapers).

- Beam clipping in telescope may be unavoidable for edge detectors of array.

  Consequences are:

    detector sees increased portion of on-board emission.

    FOV is degraded with added diffraction 'wings'

  1st results show background more serious than FOV effect.

- Model could be used to monitor all proposed apertures as the design evolves.

More on detector model (N0015).

Winston cone (App. Opt. Vol.15, No.1,p53).

Modifies 'directivity' of detector (response vs. angle not top-hat), but remains an **incoherent** detector.

Longest wavelength channel.

input aperture r_1=5mm (matched to Airy disc, F/5)

output aperture $r_2=\sin\theta . r_1$

=0.15mm for 1/e^2 clipping

For cone throughput require $\lambda/(2\, r_2) < 1.7$

$\Rightarrow \lambda < 0.5$ mm

This is the wavelength up to which the cone can be used as an incoherent concentrator with high efficiency.

From N0015.01:

Capability **Method**	**Multiple apertures**	**Aperture shape**	**Aperture tilt**	**Geometric aberrations**
Fourier analysis (ref.1)	No	Yes	No	No
Beam modes	Yes	Yes (ref.2) but no e.g.'s of non-circular cases	No	Yes, but seldom required (ref.3)
field decomposition	Yes	Yes	Yes	Yes

More on detector model (N0015).

Winston cone (App. Opt. Vol.15, No.1,p53).

Modifies 'directivity' of detector (response vs. angle not top-hat), but remains an **incoherent** detector.

Longest wavelength channel.

input aperture r_1=5mm (matched to Airy disc, F/5)

output aperture $r_2=\sin\theta.r_1$

=0.15mm for 1/e^2 clipping

For cone throughput require $\lambda/(2\,r_2) < 1.7$

$\Rightarrow \lambda < 0.5$ mm

This is the wavelength up to which the cone can be used as an incoherent concentrator with high efficiency.

From N0015.01:

Capability **Method**	**Multiple apertures**	**Aperture shape**	**Aperture tilt**	**Geometric aberrations**
Fourier analysis (ref.1)	No	Yes	No	No
Beam modes	Yes	Yes (ref.2) but no e.g.'s of non-circular cases	No	Yes, but seldom required (ref.3)
field decomposition	Yes	Yes	Yes	Yes

BOL	FIRST Bolometer	Doc No:
	Title: The FTS option for SPEC-BOL	Date: 8-Sep-97
	Author B. Swinyard, M. Griffin.	Page 1 of 12

I) INTRODUCTION:

Fourier Transform Spectroscopy offers some notable advantages over what might be termed mono-chromating spectroscopy i.e. gratings or Fabry-Perots. The two most often quoted are the so called muliplex advantage - that is all of the spectrum is measured all of the time - and the throughput, or etendue, advantage - i.e. no slit is required. However, when comparisons with grating instruments are made, both these are generally based on instruments in which only one order from the grating is measured using a single detector and the optics are not diffraction limited. In real instruments multiple orders from the grating are measured using arrays of detectors and, in the far infrared (FIR) or sub-millimetre (SMM), the optical system, and therefore the system throughput, is almost always diffraction limited: in this case these advantages are not so readily apparent. In addition, in the situation where a warm telescope is employed, the instrument performance is limited by the background power from the telescope itself in the waveband of interest. A more detailed study using real instrument parameters is thus required to compare the sensitivity of the two types of instrument - this is the subject of section II of the current note.

If a Fourier transform spectrometer (FTS) can be shown to be competitive with an equivalent grating spectrometer, there are still some real practical advantages to using this type of instrument in the FIR and SMM wavebands over and above the "multiplex" and "throughput" advantages usually referred to; these are laid out in section III. There are also some system implications and practical difficulties with this type of instrument - most obviously the mirror drive mechanism. Some notes on this are given in section IV.

Finally the case for an FTS over a grating for the SPEC-BOL is summarised in section V and some open questions discussed.

II) MODEL FTS FOR SPEC-BOL

Figure 1 shows an outline design for an FTS instrument for SPEC BOL. At this stage it is only included to allow a straightforward interpretation of the various parameters that will be included in the performance model. Obviously a more detailed optical layout will be necessary in order to check out the space requirements.

II.i Assumptions for the comparison between the grating and FTS instruments.

The following three subsections give the assumptions that have been used to calculate the performance of the grating and FTS options for the SPEC-BOL. In addition it is assumed that the baseline arrangement will have four temperature stages: 15°K for the fore optics; 4°K for the main optics and the grating or FTS; 2°K for the refocussing optics and bandpass filters and <300°mK for the detectors.

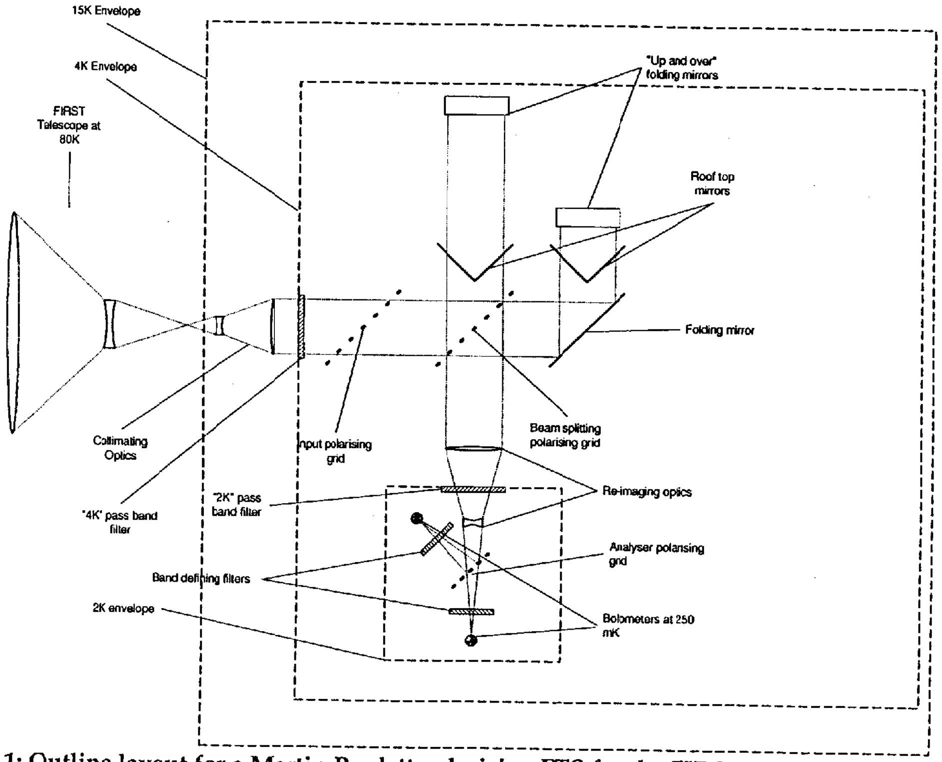


Figure 1: Outline layout for a Martin-Puplett polarising FTS for the FIRST-BOL instrument.

II.i.i General

Telescope	Diameter	3.5 m
	Temperature	80°K
	Emissivity	0.04
	Transmission	0.96
	Point source efficiency	0.7
Bolometers	Quantum efficiency	0.8
	Feed efficiency	1.0
All mirrors	Reflectivity	0.99
	Emissivity	0.01
Throughput	AΩ	λ^2

II.i.ii Grating Specific

Grating 1	Efficiency	0.6	
	Effective emissivity	0.4	
	Diffraction loss	0.2	
Grating 2 (cross dispersed only)	Efficiency	0.3	(Due to polarisation of beam from grating 1)
	Diffraction loss	0.2	
	Effective emissivity	0.4	
Filters:	15 K input filter	$t = 0.9$	
		$\varepsilon = 0.1$	in band
		$\varepsilon = \mathrm{TBD}$	out of band
	2 K blocker HP	$t = 0.9$	
		$\varepsilon = 0.1$	in band
		$\varepsilon = \mathrm{TBD}$	out of band
	2 K blocker LP	$t = 0.9$	
		$\varepsilon = 0.1$	in band
		$\varepsilon = \mathrm{TBD}$	out of band
	2 K bandpass	$t = 0.7$	
		$\varepsilon = 0.1$	in band
		$\varepsilon = \mathrm{TBD}$	out of band
		bandwidth=$\lambda/40$	
Spectral resolution		$\lambda/\Delta\lambda = 400$ at 250 μm	

Observing overhead	1.5 for single grating A bit less for cross dispersed
Chopping factor	0.45
Number of detectors	40 (two rows of 20) for single grating option TBD for cross-dispersed option

II.i.iii FTS specific

Polarisers:	Input	t = 0.5 (assume 2nd port not used for signals) ε = 0.04
	Beam divider	efficiency = 0.96 ε = 0.04
	Analyser	t = 0.5 (both ports used - one for each band) ε = 0.04
Filters:	15-K blocker	t = 0.9 (0 - 70 cm^{-1}) ε = 0.1
	4 K blocker	t = 0.9 ε = 0.1
	2 K blocker	t = 0.9 ε = 0.1
	2 K bandpass	t = 0.7 ε = 0.1 bandwidth 1 = 25-38 cm^{-1} bandwidth 2 = 38-50 cm^{-1}
Electrical filtering		efficiency = 0.8
<Cos^2> modulation		efficiency = 0.5
2nd input port:	Black body	T (adjustable) = 4°K nominal ε = 1

Other parameters will be as for grating except chopper not needed

II.ii Results of Mathcad calculations of the FTS sensitivity

Using the assumptions detailed above, a Mathcad calculation of the performance of an FTS has been run (see appendix A). To evaluate the sensitivity of the instrument to the raw detector NEPs, values of the NEP of 1,3 and 5x10^{-17} W Hz$^{-1/2}$ were used to calculate the limiting flux density and line strengths in each detector band. Also a sensitivity analysis was carried out into the affect of having only three temperature stages i.e. removing the "4°K" stage, and varying the temperature of the "non-2°K" portion of the instrument. This simulates the situation whereby the spacecraft is able to offer an optical bench at lower than 15°K. Three temperatures were tested: 10, 8 and 6°K.

The results are presented in tables 1 through 3. In the tables the temperature designated as "Nom." represents the nominal situation with a 15°K and a 4°K stage before the 2°K stage.

	Band 1 38-50 cm^{-1} (centre band ~225 µm)				Band 2 25-38 cm^{-1} (centre band ~320 µm)			
Temp ⇒ Detector NEP ⇓	Nom.	10	8	6	Nom.	10	8	6
1x10^{-17}	4.90	4.93	4.83	4.81	4.76	4.85	4.63	4.53
3x10^{-17}	5.66	5.68	5.60	5.58	5.54	5.61	5.42	5.34
5x10^{-17}	6.93	6.95	6.88	6.87	6.83	6.89	6.74	6.67

Table 1. Instrument NEPs in 10^{-17} W Hz$^{-1/2}$ as a function of detector NEP, optical bench temperature and waveband.

	Band 1 38-50 cm^{-1} (centre band ~225 µm)				Band 2 25-38 cm^{-1} (centre band ~320 µm)			
Temp ⇒ Detector NEP ⇓	Nom.	10	8	6	Nom.	10	8	6
1x10^{-17}	0.086	0.085	0.084	0.084	0.118	0.120	0.114	0.112
3x10^{-17}	0.099	0.098	0.097	0.097	0.137	0.139	0.134	0.132
5x10^{-17}	0.121	0.120	0.119	0.119	0.169	0.170	0.166	0.165

Table 2. Limiting flux densities in Jy quoted as 1-sigma in 1-hour as a function of detector NEP, optical bench temperature and waveband.

	Band 1 38-50 cm^{-1} (centre band ~225 µm)				Band 2 25-38 cm^{-1} (centre band ~320 µm)			
Temp ⇒ Detector NEP ⇓	Nom.	10	8	6	Nom.	10	8	6
1x10^{-17}	2.85	2.83	2.79	2.78	2.75	2.80	2.67	2.62

$3x10^{-17}$	3.29	3.27	3.23	3.23	3.20	3.24	3.13	3.09
$5x10^{-17}$	4.02	4.01	3.98	3.97	3.95	3.98	3.90	3.86

Table 3. Limiting line strengths in 10^{-18} W m^{-2} quoted as 1-sigma in 1-hour as a function of detector NEP, optical bench temperature and waveband.

The figures given here should be compared to the results of the single grating study (see Mathcad model from Matt) which gave a limiting flux of 0.085 Jy and a limiting line strength of $2.1x10^{-18}$ W m^{-2} for a full spectral survey and 0.049 Jy and $1.2x10^{-18}$ W m^{-2} for detection of a line at known wavelength; all these figures are for a wavelength of 300 μm.

III) ADVANTAGES OF AN FTS FOR SPEC-BOL

III.i. Much easier detector NEP requirement.

As shown in section II, the broad instantaneous passband of the FTS compared with the grating instrument, means that the achievable sensitivity is much less dependent on the detector NEP. In fact an increase in detector NEP from $1x10^{-17}$ to as much as $5x10^{-17}$ W Hz$^{-1/2}$ only results in a 40% increase in the limiting flux. The basic NEP requirement is thus easier to meet and the instrument is intrinsically less susceptible to changes in the detector NEP caused by changes in operating conditions in orbit. A detector temperature of 300 mK can also now be contemplated, obviating the need for a dilution fridge.

III.ii. Adjustable spectral resolution

The spectral resolution of the FTS is easily adjusted by changing the scan range of the moving mirror. In the case of the BOL, it could be set at an value between ~10 and even up to ~1000, depending on the scientific application and the space and power constraints on the instrument design. This also has the advantage that the limiting detectable continuum flux decreases linearly with the resolving power employed. Thus the same instrument can be used to obtain narrow band photometry on faint objects (R~10 F_{LIM}~ 2-3 mJ) and medium resolution spectroscopy on brighter objects (R~400 F_{LIM} ~90-120 mJ). Note however that this does not affect the limiting detectable line strength.

III.iii. Imaging spectroscopy

For the modest resolution requirement of the BOL, the FTS is compatible with imaging spectroscopy using a compact array at the focal plane.

III.iv. Immunity to stray light and spectral purity

Only radiation that is modulated by the instrument is detected as truly part of the source spectrum. Thus any radiation, either in or out of band, not coming via the instrument but reaching the detector via an unauthorised route contributes to the detector NEP only and does not contaminate the source spectrum. Also any out of band leaks in any of the filtering will be encoded spectrally and not seen as in band spectral features - unlike the situation with the grating instrument.

The broad band nature of the instrument means that most - essentially **all** - of the background limited NEP is contributed by the primary telescope and other sources of straylight would have to be very large indeed to have a significant impact on the overall NEP (see section II table nnn). The instrument is therefore very much less sensitive to the straylight environment than the grating.

III.v. No chopper required

An FTS, operated in continuous scan mode, requires no chopping, giving an increase in observing efficiency and greater reliability.

III.vi. Simplified calibration

The second input port can have an accurately calibrated black body source in it, thus the source spectrum can be constantly referred to a relative calibration standard if required. This makes removal of detector or amplifier drifts very much easier to remove. Also the wavelength calibration is inherent in the measurement technique provided the Fourier transform is sampled correctly. Any phase errors, shifts etc. only affect the derived power at a particular wavelength.

III.vii. Well behaved instrument response function

Given that any phase errors etc. have been dealt with in the Fourier transform, the basic scanning function for an FTS is a SINC function. This has undesirable side lobes in its raw form - however, it can be adjusted by apodisation and has the important property that it has the same FWHM at all wavelengths. Although to first order this is also true for grating instruments within a single order, in practice multiple orders are used and the width also changes with diffraction angle causing small changes within a single order.

III.viii. Wavelength coverage.

The wavelength coverage of an FTS is, within a waveband that can be efficiently transmitted by the polarising grids, governed only by the final filters on the detectors. It is thus easy to extend the wavelength coverage to higher or lower wavelengths. In a grating spectrometer, once the design waveband has been fixed, the wavelength coverage can only be changed by the addition of extra detectors at fixed diffraction angles - this will always prove problematic.

III.ix. Limited variation in sensitivity with wavelength

For both the FTS and grating instruments there will be a variation in sensitivity as a function of wavelength caused by the use of bandpass filtering i.e. the filters will not be perfect top hats. In the case of the grating there is a second variation in sensitivity caused by the changes in efficiency for wavelengths not at the blaze wavelength - this could be as much as a factor of 2 between the blaze wavelength and the edge of the diffraction order. The bandpass filtering for the grating will also have to be much narrower than for the FTS and, therefore, the efficiency variations will have a higher frequency as a function of wavelength causing difficulties in "stitching" an end-to-end spectrum together.

IV OPERATING PARAMETERS AND SYSTEM REQUIREMENTS FOR THE FTS

IV.i Operating parameters

In this section the global operating parameters (scan range, wavelength coverage etc. etc.) are given for a model FTS for the SPEC-BOL. In section IV.ii the implications of these for the drive mechanism are discussed and in section IV.iii the implications of the operating parameters and the drive mechanism on the system requirements (mass, power etc.) are considered.

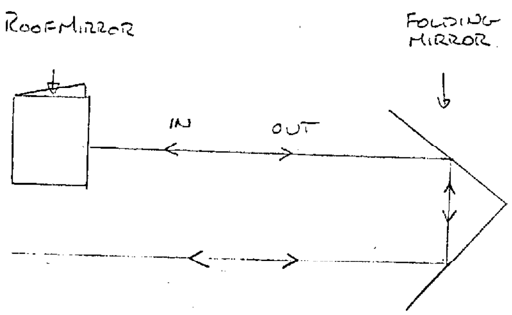
Wavelength coverage	$\lambda = 200 - 400\ \mu\text{m}$ or $25 - 50\ \text{cm}^{-1}$
Required resolution	$\lambda/\Delta\lambda = 400$ at $250\ \mu\text{m}$ ($40\ \text{cm}^{-1}$) $\Rightarrow \Delta\sigma = 0.1\ \text{cm}^{-1}$
Optical path difference	$\sigma = 1/(2L) \Rightarrow L = 5\ \text{cm}$ assume 6 cm for scan length to allow for measure of zero path difference
Linear travel	(6 cm)/8 = 7.5 mm - or about 1.5 for R = 1000. A factor 8 folding can be achieved with "up and over" folding flats (see figure 2).
Nyqvist sampling rate:	$\Delta x_{max} = 1/(2\sigma_{max})$ $\Rightarrow \Delta x_{max} = 1/(2 \times 38) = 0.013$ cm for band 2 $\Rightarrow \Delta x_{max} = 1/(2 \times 50) = 0.010$ cm for band 1
Over-sampling factor	3

	$\Rightarrow \Delta x = 43\ \mu m$ band 2 $\Rightarrow \Delta x = 33\ \mu m$ band 1
No. of samples per interferogram	$N_{samp} = (6\ cm)/(43\ \mu m) = 1395$ band 2 $N_{samp} = (6\ cm)/(33\ \mu m) = 1818$ band 1
Audio frequencies	$f = v_{opd}\sigma$ where v_{opd} is the rate of change of the optical path difference.
Max. allowed audio freq.	20 Hz (from assumed detector response) $\Rightarrow v_{opd} = 20/50 = 0.4\ cm\ s^{-1}$ $\Rightarrow v_{mirrors} = v_{opd}/8 = 0.05\ cm\ s^{-1}$
Audio freq. band	$25 - 38\ cm^{-1} \rightarrow 10 - 15$ Hz $38 - 50\ cm^{-1} \rightarrow 15 - 20$ Hz
Time per scan	$t_{scan} = (6\ cm)/(0.4\ cm\ s^{-1}) = 15\ s$
Sampling rate	(1395 samples)/(15 s) = 93 samples s^{-1} - band 2 (1818 samples)/(15 s) = 121 samples s^{-1} - band 1
Number of detectors	40 (two arrays of 20)
Position measurement:	Accuracy required = 1 μm Sampling required = same as detector in band 1
Internal read-out rate:	Band 2: 93 Hz x 20 dets = 1.86 kHz Band 1: 121 Hz x 20 dets = 2.42 kHz Position measurement = 0.12 kHz Total = 4.39 kHz

IV.ii Requirements for the drive mechanism

The major difficulty in implementing an FTS for the BOL will be in building a mechanism working at cryogenic temperatures that will move the mirrors back and forth whilst keeping them parallel with each other. One option would be to adapt the existing ISO grating drive motor to drive a pantagraph arrangement similar to used on SAFIRE. The angular movement required, if the beam on which the mirrors are mounted has a 10 cm half width, will be about $\pm 2.9°$. Inspection of the grating mechanism power requirements shows that about 2 mW is needed to drive to $\pm 2.9°$ (CHECK THIS) with a more of less linear angle vs. power curve in between. The average power consumption over a movement cycle will therefore be 1 mW - an allowance should be made however for the fact that the FTS mirrors are likely to be heavier than the grating.

Another way of estimating the power required is the scale from an existing mechanism. The SAFIRE FTS has mirrors of mass 5 Kg, driven at a velocity 20.3 mm s^{-1} with a power consumption of 13W. If this is scaled to mirrors of total mass 0.8 Kg (10 cm diameter 2 cm thick) with a velocity of 0.5 mm s^{-1}: linearly with mass and by the square of the velocity - then the power consumption for BOL would be 1.25 mW. This is in the same range as for the grating mechanism. Allowing for unforeseen inefficiencies (bearings etc.) the power requirement can be set conservatively at 2 mW for the present purposes, but a more detailed study will be required for the IID input.



x 2 is achieved by moving both mirrors
So we get
2×2×2 = 8 times the optical path difference for each movement of the roof mirrors.

Figure 2: The folding achieved using "up and over" mirrors

IV.iii System Requirements Compared with Grating Option

Mass	Same as grating or less
Volume	Same as grating or less
Thermal dissipation	Dissipation from the mechanism is likely to be higher - first-cut guess 2 mW at 4 K in operation - see above (cf. 0.6 mW for grating) .
Duty Cycle	Operation for 50% of BOL time (1/6 of mission time) Peak ≅ 2 mW (when averaged over 15-sec. interval) Average over mission = 2/6 mW Minimum = 0

48

Operating modes:	Continuous back and forth scanning Scan time = 15 sec max.; 2 sec. min (narrow band photometry) Pointing fixed for a given scan At least five scans per spatial point on the sky If fully sampled map needed, may need to do raster-(jiggle)-map as for photometer
Numbers of wires:	About same as for grating
Bit rate	4390 x 14 = 61 kbs - note less bits are assumed than required for grating owing to low dynamic range (2).
Telemetry rate:	The low dynamic range also offers scope a larger degree of data compression than in the case of the grating option. If it is assumed that a compression factor of 3 is easy → 20 kbs

V SUMMARY OF THE CASE FOR AN FTS AND OPEN QUESTIONS.

Performance models of both a single grating spectrometer and a Fourier transform spectrometer have been constructed using Mathcad. These show, given the same input assumptions, that the FTS will be as sensitive as the grating for full spectral surveys of point sources, but a factor of two less sensitive for detection of a line at known wavelength. It is then a matter of scientific judgement as to which of these modes will have the highest priority for FIRST.

Given that the FTS is competitive in terms of sensitivity, the practical advantages of an FTS over a grating have been outlined in section II above. The major advantage of the FTS is its insensitivity to both changes in the raw detector NEP and changes in the level of straylight. For the grating however, the straylight level would have to be below a few tens of femtowatts - an unprecedented level in sub-millimetre instrumentation - and any change in the detector performance feeds linearly into the achievable sensitivity.

Some practical difficulties and open questions remain to be solved for the FTS:

- Mechanism design and power dissipation - is 2 mW achievable? If so does it meet the system thermal design requirements? How reliable will it be?

- Measurement of the mirror position - are LVDTs sufficient? If not is it feasible to think of system based on a solid-state laser for position measurement?

- How big a field can we accommodate with good fringe contrast?

- What is the optimum scan rate? Is there scope for using signal freq. < 10 Hz?

- Can bolometers with an operating frequency of 20 Hz and NEP of $<5\times10^{-17}$ W $\mathrm{Hz}^{-1/2}$ be made to work at 300 mK?

- What wavelength range and resolution should we aim for?

BOL Consortium

Project management	RAL
Detector subsystem	QMW
Structure	MSSL/ROE
Chopper	ROE
AIV/Ground calibration	RAL (with participation of all H/W groups)
EGSE	ICSTM
ICC Science Centre	ICSTM
ICC Operations Centre	RAL
Refrigerator	GRENOBLE CEA, ~~Saclay~~ or Grenoble (CRTBT)
Analogue electronics	CEA; IAS ?
Optics, spectrometer mechanism	LAS
Bolometric sensors	Caltech/Goddard or CEA
Digital electronics	IFSI
Instrument simulator	Stockholm Obs.
Other possible contributions	Canada, Spain

BOL Consortium ~~Management~~ ORGANISATION

PI	Matt Griffin, QMW
Co-PI	Laurent Vigroux, CEA
Project Manager	Ken King, RAL
Project Scientists	UK: Walter Gear, MSSL Fr: TBD
Instrument Scientists	UK: Bruce Swinyard, RAL Fr: TBD
Systems Engineers	UK: Colin Cunningham, ROE Fr: TBD
ICC Director	Michael Rowan-Robinson, IC

← one for Fr tusa ?

~~SOFTWARE~~ OPERATIONS SYSTEMS ?

Some responsibilities of the Project Scientists:

1. Specify and update scientific requirements
2. Oversee instrument design/capabilities wrt these goals
3. Specify observing modes, calibration strategies, ground-testing and data-reduction requirements
4. Co-ordinate proposal scientific case and Guaranteed Time scientific programme
5. Etc.

Some responsibilities of the Instrument Scientists:

1. Define and update detailed specifications for all subsystems
2. Design instrument calibration and ground-testing facility
3. Lead major instrument design reviews
4. Etc.

SYSTEMS ENGINEERS

Some responsibilities of the ~~Instrument Scientists~~:

1. Oversee specification and control of all internal and external interfaces
2. Identify and take action on actual or potential problems at system level
3. Establish necessary procedures/teams/mechanisms for monitoring system aspects of instrument design, construction, calibration, operation
4. Etc.

NOV 27 TECHNICAL
BRIEFING
AT ESTEC

TECHNICAL

INSTRUMENT
SCIENTISTS

PROJECT
SCIENTISTS

SYSTEMS
ENGINEERS

OVERALL CO-ORDINATOR: BMS

MANAGERIAL / FINANCIAL

PI
Co-PI
PM
+ NATIONAL REPS.

NEW NAME
FOR THE
BOL
→ COMPETITION
(BY MID. DEC)

PROPOSAL <
SCIENTIFIC
TECHNICAL
MANAGERIAL / FINANCIAL

TECH SPEC

SCIENTIFIC:

EXTRAGALACTIC <
HIGH Z < ROWAN-ROBINSON ✓
FRANCESCHINI ✓
MR BEAN ?
LOCAL — GEAR ✓, MADDEN ✓

GALACTIC <
SF < ANDRÉ ✓
SARACENO ✓
ISM — BALUTEAU, COX?
~~CS MATTER~~
(EVOLVED STARS) — BARLOW ?

SOLAR SYSTEM — TBD < Th. ENCRENAZ ?
E. LELLOUCH ?
etc ?

OVERALL CO-ORDINATOR MJG ✓ + LV ✓

- CONC. ON UNIQUE SCIENCE FOR FIRST

BOLOMETER PROJECT
WWW PAGES

http://www2.ssd.rl.ac.uk/bol

USER: BOL

PASSWORD: GRIFFIN97

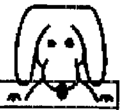
Contents:

Names & Address Database
Document Index
Action List

+

Browser Plug-ins & Readers
- Adobe .pdf
- Ms Word
- Ms Excel

FIRST Bolometer - Action List Selection



Action	Who	Due	Status	Description
OPT04-08	MJG	04 Jul 1997	Open	Provide information on dilution fridge dimensions
OPT04-11	KD ,EA	04 Jul 1997	Open	Write brief summaries of the new optical designs and e-mail/fax to BMS for inclusion in short document
OPT04-15	BMS ,MJG	18 Jul 1997	Open	Specify parameters and assumptions for straylight analysis
OPT04-09	CRC ,BrM ,IDH	18 Jul 1997	Open	Revise mass estimates and thermal model using new baseline optical designs and address problem of the FET module
OPT04-07	CRC ,BrM	18 Jul 1997	Open	Produce diagram for IID summarising characteristics of the BOL thermal model
OPT04-06	PARA	18 Jul 1997	Open	Provide reflectivity data on QMW black material
OPT04-05	MJG	18 Jul 1997	Open	Raise with ESA possible need to peak up before point source observations
OPT04-04	KJK	18 Jul 1997	Open	Provide information on power dissipation of LWS Grating drive in "grating chopping" mode
OPT04-03	MJG	18 Jul 1997	Open	Get information from ESA on telescope surface roughness
OPT04-01	CRC	31 Jul 1997	Open	Write Short Note on Glitch identification and removal
OPT04-12	KD ,EA ,BMS	31 Jul 1997	Open	Finalise and write more detailed notes on the optical designs, including alignment tolerances
OPT04-02	CRC	31 Jul 1997	Open	Write note on data sampling and dynamic range and implicatios for on-board A-D conversion (inc. glitch removal, ac/dc coupling)
OPT04-18	IDH	31 Jul 1997	Open	Write summary of 3He and ADR technology relevant to the BOL (in collaboration with Lionel Duband, if possible)
OPT04-10	BMS	31 Jul 1997	Open	Model efficiency of two-grating system with Russian grating analysis code
UK04-09	MC	27 Aug 1997	Open	Specify what apertures/temperatures are useable
UK04-19	BMS	29 Aug 1997	Open	Look at option of using something similar to the LWS grating mechanism to drive FTS (esp. power dissipation)
IID03-11	MJG	12 Sep 1997	Open	Send FIRST Alignment Plan to RAL/ROE
UK04-18	MJG	12 Sep 1997	Open	Estimate maximum source strength we need to observe and corresponding signal level
UK04-21	BMS ,MJG	12 Sep 1997	Open	Revise and extend BMS's FTS sensitivity model
IID03-10	MJG ,EA ,MC	12 Sep 1997	Open	Comment on BOL preferences for telescope parameters in draft Telescope Specification
IID03-08	MJG	12 Sep 1997	Open	Update IID Ch. 4 and send to ESA
IID03-07	MJG	12 Sep 1997	Open	Update IID harness table with maximum allowed, rather than estimated resistances
UK04-17	MJG	12 Sep 1997	Open	Estimate allowable telescope temperature fluctuation and give results to CRC for data handling analysis
IID03-05	CRC	22 Sep 1997	Open	Make more realistic estimate of chopper power dissipation
UK04-12	CRC	30 Sep 1997	Open	Arrange for ROE to do outline design study on the question of whether the chopper should/can be capable of (I) carrying out jiggle motions for mapping; (ii) peaking up internally
IID03-04	CRC ,PRH	10 Oct 1997	Open	Update BOL1 mass breakdown and summarise in a form suitable for input to ESA

IID03-03	MJG	10 Oct 1997	Open	Provide details of all dilution cooler interfaces to ESA
IID03-02	MJG	10 Oct 1997	Open	Write note on PHOC-BOL "partner mode" and send to Albrecht Poglitsch for comment
IID03-01	CRC	10 Oct 1997	Open	Produce block diagram of BOL suitable for IID section 5.10.2.1
IID03-06	MJG	10 Oct 1997	Open	Provide ESA with update on BOL straylight model
IID03-09	CRC ,BrM	01 Jan 1998	Open	Run BOL thermal model with PHOC mass data from Albrecht Poglitsch, whe info provided
IID03-12	MJG	01 Jan 1998	Open	Summarise details of BOL data rate requirements for IID, when Harm Schaap provides template table

Please Click on any Action Number to get more details

Help Home

Send comments to: Bolometer Project Office

Last modified - 1997 July 1st

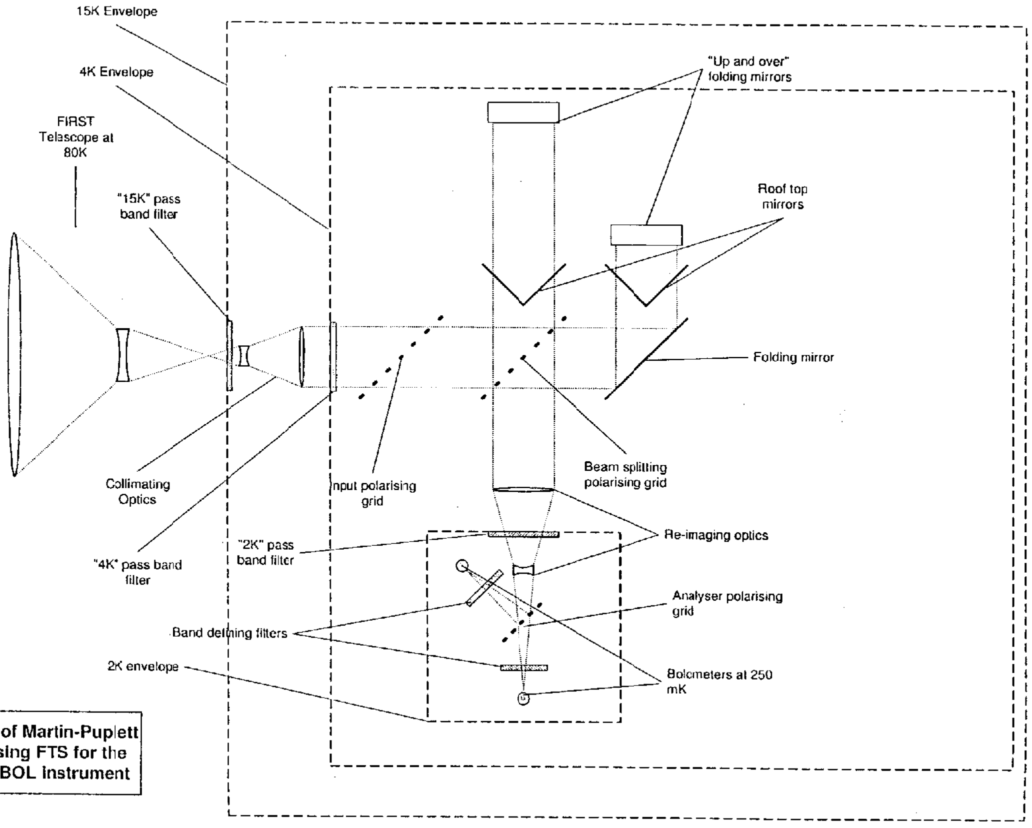
IWG04-1	MJG	To check position and size of BOL FOV on M3
IWG04-2	EA, KD	To decide on f-number at entrance to the photometer and spectrometer f/4 Closed
IWG04-3	MJG	To push ESA to provide the telescope specification.
IWG04-4	FM	To do a first order opto-mechanical layout of the instrument
IWG04-5		To provide space envelope for the cooler.

FTS AND GRATING OPTIONS:
SCIENTIFIC AND TECHNICAL CONSTRAINTS

- Scientific:
  1. Relative priorities of two observing modes:
     - Scanning full spectral range
     - Measuring line or narrow feature of known λ
     - Emphasis for BOL is currently on full scans
     - Relative sensitivities of HET and BOL for these two modes must be examined in detail
  2. Importance of imaging spectroscopy:
     - Difficult with grating
     - Easier with FTS
     - Useful for proper background subtraction even for point source observations
  3. Importance of adjustable resolution:
     - Not possible with grating
     - Easy with FTS
     - Has been emphasised by AGN and Solar System people
  4. Max. resolution required:
     - ~ 400 for grating
     - Possibly higher for FTS
     - How useful is this?
- Technical:
  1. Mass, volume
  2. Data rate
  3. Mirror drive mechanism
     - Power dissipation (should be < ~ 2 mW)
     - Microphonics
     - Lifetime, reliability
  4. Operating modes and data processing
  5. Best FTS design for BOL requirements

Marsielles 22/24 September 1997
Fourier Transform Spectrometer for BOL

Conceptual Design



Outline of Martin-Puplett polarising FTS for the FIRST BOL instrument

Performance - 1. NEPs

	Band 1 38-50 cm^{-1} (centre band ~225 μm)				Band 2 25-38 cm^{-1} (centre band ~320 μm)			
Temp ⇒ Detector NEP ⇓	Nom.	10	8	6	Nom.	10	8	6
$1x10^{-17}$	4.90	4.93	4.83	4.81	4.76	4.85	4.63	4.53
$3x10^{-17}$	5.66	5.68	5.60	5.58	5.54	5.61	5.42	5.34
$5x10^{-17}$	6.93	6.95	6.88	6.87	6.83	6.89	6.74	6.67

Instrument NEPs in 10^{-17} W $Hz^{-1/2}$ as a function of detector NEP, optical bench temperature and waveband.

Performance - 2. Limiting fluxes

	Band 1 38-50 cm^{-1} (centre band ~225 μm)				Band 2 25-38 cm^{-1} (centre band ~320 μm)			
Temp ⇒ Detector NEP ⇓	Nom.	10	8	6	Nom.	10	8	6
1x10^{-17}	0.086	0.085	0.084	0.084	0.118	0.120	0.114	0.112
3x10^{-17}	0.099	0.098	0.097	0.097	0.137	0.139	0.134	0.132
5x10^{-17}	0.121	0.120	0.119	0.119	0.169	0.170	0.166	0.165

Limiting flux densities in Jy quoted as 1-sigma in 1-hour as a function of detector NEP, optical bench temperature and waveband.

Performance - 3. Limiting line strengths

	Band 1 38-50 cm^{-1} (centre band ~225 μm)				Band 2 25-38 cm^{-1} (centre band ~320 μm)			
Temp ⇒ Detector NEP ⇓	Nom.	10	8	6	Nom.	10	8	6
$1x10^{-17}$	2.85	2.83	2.79	2.78	2.75	2.80	2.67	2.62
$3x10^{-17}$	3.29	3.27	3.23	3.23	3.20	3.24	3.13	3.09
$5x10^{-17}$	4.02	4.01	3.98	3.97	3.95	3.98	3.90	3.86

Limiting line strengths in 10^{-18} W m^{-2} quoted as 1-sigma in 1-hour as a function of detector NEP, optical bench temperature and waveband.

Grating Performance

Full scan - 85 mJy and 2.1 x 10^{-18} W m^{-2}
Known line - 49 mJy and $1.2x10^{-18}$ W m^{-2}

Advantages of the FTS

- Much easier detector NEP requirement.
- Adjustable spectral resolution
- Imaging spectroscopy
- Immunity to stray light and spectral purity
- No chopper required
- Simplified calibration
- Well behaved instrument response function
- Wavelength coverage.
- Limited variation in sensitivity with wavelength

Major System Impacts

- Bit rate ~60 kbits/sec with no compression - given the limited dynamic range required we should be able to get this down to 20 kbits/sec.
- Mechanism power dissipation ~ 2 mW constantly during operation. But should be able to operate at a higher temperature.
- Everything else remains essentially the same as for the grating option.

DETECTOR OPERATING TEMPERATURE REQUIREMENTS

- Photometer (photon noise limited):

$NEP_{PH} \times 10^{-17}$ ($W\ Hz^{-1/2}$)		
250 µm	350 µm	500 µm
12	9	7

  - Speed of response: Ideally 5 Hz ($\tau \approx 30$ ms)
    Could live with 3 Hz ($\tau \approx 50$ ms)
  - This performance should be easily achievable at 300 mK

- Grating spectrometer (detector noise limited):
  - Detector NEP target = $1 \times 10^{-17}\ W\ Hz^{-1/2}$
  - Speed of response: as for photometer
  - Should be achievable at 200 mK
  - Not clear whether it is feasible at 300 mK (but close)

- FTS spectrometer (photon noise limited):
  - $NEP_{ph} \approx 5 \times 10^{-17}\ W\ Hz^{-1/2}$
  - Speed of response: Ideally > 20 Hz ($\tau > 8$ ms)
    Could probably live with 15 Hz
    ($\tau = 11$ ms)
  - Should be achievable at 300 mK (but needs to be demonstrated).

- Cooling power: Dilution system (200 mK) : Est. 0.4 µW
  ^{3}He system (300 mK) : Est. 20 µW

- Conclusions:
  1. Detector T_{op} > 200 mK
  2. T_{op} = 300 mK probably adequate
  3. Additional cooling power of ^{3}He may allow bigger arrays to be used
  4. Dilution system doesn't need cycling

CONCLUSION

If specification on ultimate temperature
is above ≈ 260 mK

▼

→***He 3 Sorption cooler***←
could be
→***an alternative for FIRST***←

HOW TO IMPROVE TULTIMATE

Mass flow rate (<u>neglecting heat switch and support structure</u>) : • $m \% \frac{\O^2}{L}$

As a first approximation, pressure above ^{3}He bath :

- $P_{bath} \% \frac{\sqrt{m L}}{\O^2}$ (visquous regim)
- $P_{bath} \% \frac{m L}{\O^3}$ (molecular regim)

Thus $\boxed{P_{bath} \% \frac{1}{\O}}$ & $\boxed{\text{Hold time } \% \frac{L\, M_{He3}}{\O^2}}$

Example

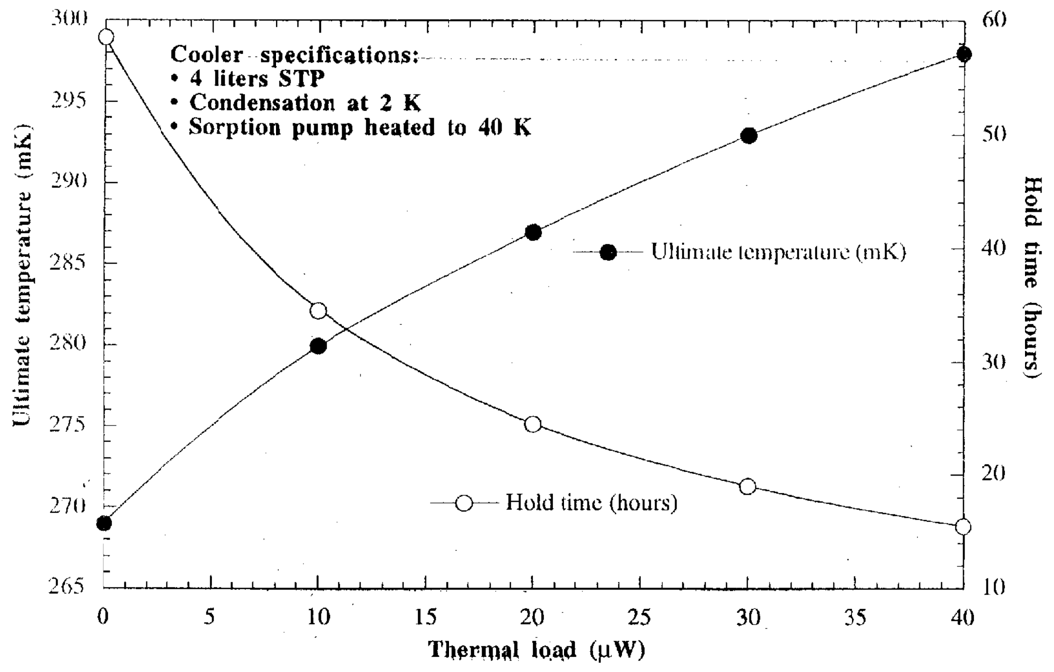
280 mK ⬇ **250 mK** **0.89 10^{-3} torr** ⬇ **0.24 10^{-3} torr** ▶ **Increase of Ø by factor 3.7** ⬇ **affect hold time by 14**

To compensate :

- increase M_{He3} ⇨ energy and power ⇗
- increase L ⇨ "cold" volume ⇗ ⇨ condensation efficiency ⇘ ⇨ hold time ⇘

[Note that load from heat switch and support structure must be taken into account - w
significantly affect above numbers]

COOLING POWER CURVE & HOLD TIME



With no applied loa

T ultimate ≈ 269 mK
Hold time ≈ 58 hour

With 1.5 µW applie

T ultimate ≈ 272 mK
Hold time = 53 hour

Lionel Duband CEA DSM/DRF

PERFORMANCE ON A TYPICAL CYCLE

Condensation phase at 2 K

- Sorption pump heated to 40 K
  - Input power to the pump : 63 mW
  - Condensation efficiency : 80 %

Low Temperature phase

- Applied heat load : 1.5 µW
  - Total heat load : 15.5 µW
  - Average power dissipated ≈ 0.8 mW
  - Ultimate temperature : 272 mK for 53 hours

Duty cycle efficiency : 93 %

Over the entire cycle, average power ≈ 2.2 mW

Full cycle ≈ 57.1 hours

Condensation phase
(1.8 hours - 3 %)
Cooldown phase
(2.3 hours - 4 %)

Low temperature phase
(53 hours - 93%)

ROUGH SIZING FOR FIRST COOLER

IDENTIFIED SPECIFICATIONS

- *T cold plate : 2 K, possibly 1.8 K*
- *Hold time / recycling time : minimum 24 h / 2 h - 48 h / 2 h better*
- *Average load on ^{4}He bath : ≤ 2 mW*
- *Peak power dissipation : TBD, we assume ≤ 20 mW*
- *Mass : < 1 Kg*
- *Dimensions : ? TBD*

4 liters STP cooler suitable

• ^{3}He charge	4 S.T.P. liters
• Pressure at 293 K	7.1 MPa (71 bars)
• Estimated weight	probably < 600 g
• Charcoal mass:	13 g
• Pump/evaporator	Stainless steel spheres Ø 46 mm / Ø 26 mm
• Pumping line	Stainless steel tube ID 10 mm total length ≈ 190 mm

Assumptions :

- Gas gap heat switch :
  improved (ratio A/L : 3 10^{-3} cm)
  ON position : 0.1 mW required

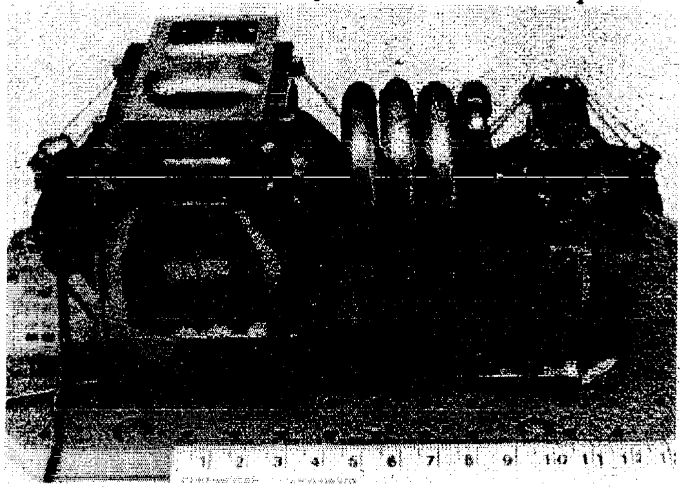
- Kevlar support structure :
  ratio A/L : 5 10^{-3} cm (= half IRTS)

- Load from detectors + wires : 1.5 µW

SPACE-BORNE ADSORPTION COOLER

IRTS ^{3}HELIUM REFRIGERATOR

*Cool bolometric infrared detectors of the Far InfRared Photometer (**FIRI***
*in the **InfRared Telescope in Space (IRTS)** to 300 mK,*
from the 2 K provided by a superfluid ^{4}He bath



Features

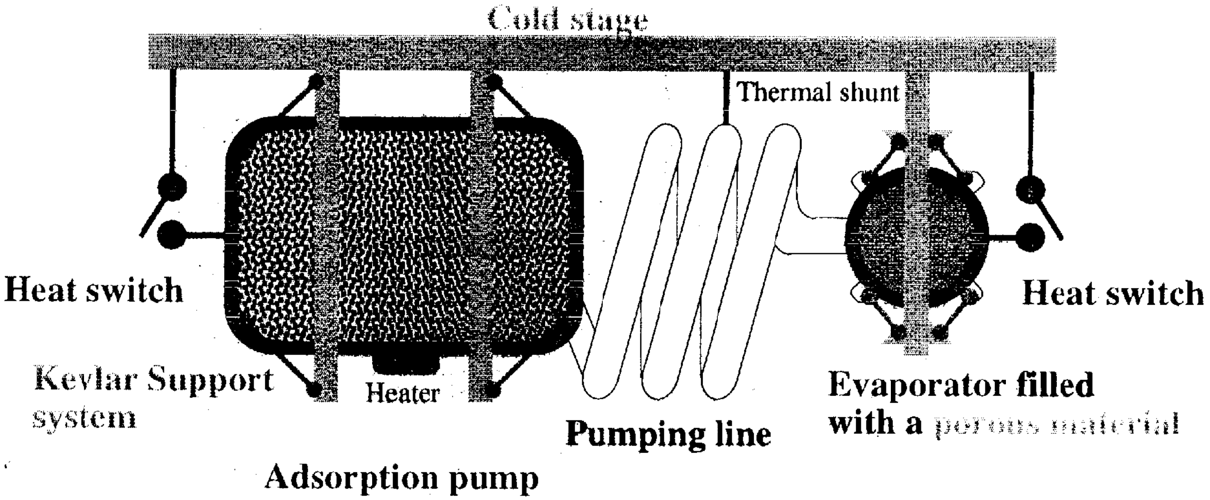
- Support system: Kevlar cords
- Liquid confinement: Silicon sponge → cooler can be recycled and operated in zero-g
- Uses two gas gap heat switches
- 10 days of cooling at 300 mK with 17 μW load
- Dissipation: 1.8 mW average on the 2K cold plate
- Total weight: 870 g

successfully launch into orbit in March 1995
on board the Japanese Space Flyer Unit (SFU)

Lionel Duband CEA DSM/DR

SPACE SYSTEM

PRINCIPLE OF OPERATION



	Pump heat switch	evaporator heat switch
Condensation phase	**OFF**	**ON**
Cooldown phase	**ON**	**OFF**
Low temperature phase	**ON**	**OFF**

THE SPACE ENVIRONMENT

Two aspects have been addressed:

❶ STRUCTURAL STRENGTH

FIRMLY SUPPORT ◀▶ MINIMISE PARASITIC HEAT LOAD

for instance → Kevlar support structure

❷ LIQUID CONFINEMEN

POROUS MATERIAL TO HOLD LIQUID BY CAPILLARY ATTRACTIO

for instance → silicon sponge

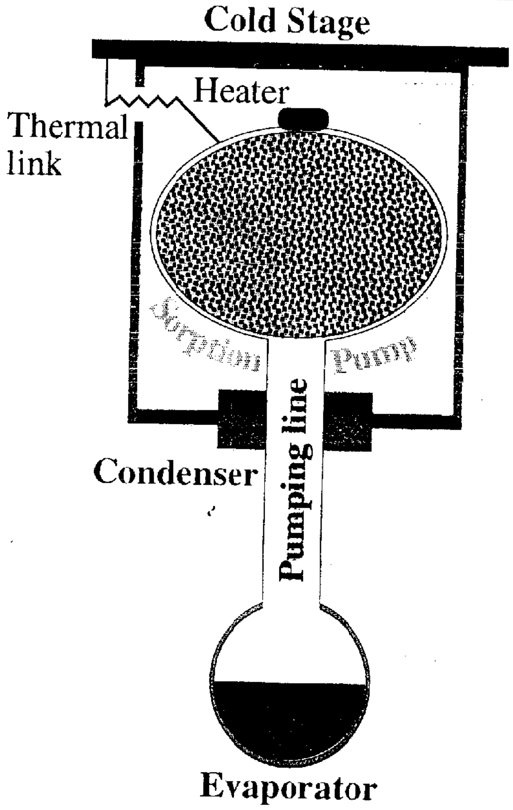
in addition
Dissipation and power consumption
→ precise knowledge and control of energies and power

FEATURES

- **No moving parts, Fully static ⇨ reliable**
- **No Vibrations**
- **Compact**
- **Good temperature stability**
- **Good duty cycle efficiency** [$\frac{\text{recycling time}}{\text{recycling time+hold time}} \geq 96\%$]
- **No mechanical or Vacuum connections required**
- **Easy to integrate, simple to operate (2 leads required)**

SUITABLE FOR ADAPTATION TO THE SPACE ENVIRONMENT

PRINCIPLE OF OPERATION
***OF AN 3HE COOLER** (self contained unit)*



Phase A:
pump is heated to about 40 K and consequently gas desorbed from the charcoal. Pressure increases until:

Liquid ^{3}He
⇩
is condensed at the condenser
⇩
falls by gravity into the evaporator

Phase B:
pump is cooled down (≤ 5 K).
gas is readsorbed
⇩
liquid helium bath is thus pumped down to obtain an evaporative cooling

The ^{3}He pressure is controlled by the adsorption pump
(pressure varies by 5 orders of magnitude)

75

CEA/DSM - Grenoble DRFMC
DEPARTEMENT DE RECHERCHE FONDAMENTALE
SUR LA MATIERE CONDENSEE

SPACE-BORNE HE 3 SORPTION COOLE

Lionel Duband

CEA DSM/DRFMC/SERVICE DES BASSES TEMPERATURES (FRANCE)]

AN OPTION FOR FIRST ?

Dilution cooler for space applications

Helium storage high or low temperature

→ tube connexions between 300K – 4K

pre cooling	Mechanical cooler	Helium cryostat			
base temperature	4 K	4 K		2 K	
Helium storage temperature	300K	300K	4 K	300 K	2K
Large tube (φ 3)	1	1	1	0	0
small tube (φ 0.5 mm)	2	2	0	3	1

Only one small tube

from the cryostat to the ~~[illegible] stage~~ outer shell

→ no requirements { of heat exchangers
{ or cold traps
{ or filter

- high temperature storage
  - same as PLANCK
  - easy flow control
  - tubing between 300K and 2K

- Low temperature storage
  - No problems of blocking
  - Only one small output tube
  - Flow control with heaters

  → already tested in laboratory
  but with high temperature flowmeter

- Volume of storage container

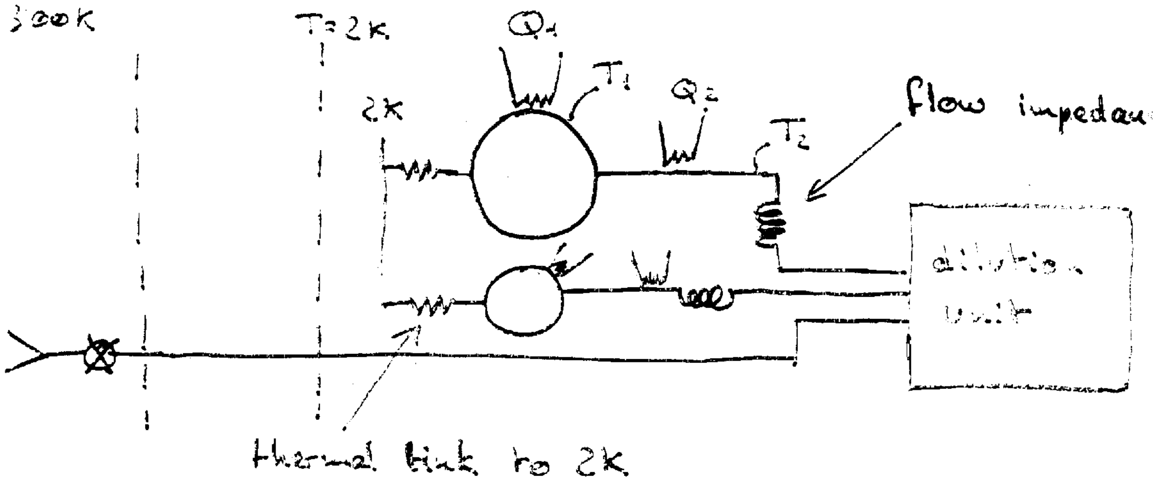
  → decreases as operating temperature increases

If you need $T \gtrsim 300\,\mathrm{mK}$
If you have enough power at 2K
If you do not make continuous measurements
) use ^{3}He fridge

otherwise → use dilution fridge

Typical volumes for 2 years operation

		PLANCK	FIRST		
Temperature		100 mK	150 mK	250 mK	25
mass of detectors ~~[illegible] plan~~		1.5 kg	2 kg	2 kg	2 k
typical power		200 nW	300 nW	1 μW	300 n
flow	^{3}He	4 μmol/s	2 μmol/s	2 μmol/s	1 μ
	^{4}He	16 μmol/s	8 μmol/s	8 μmol/s	4 μ
high T container	^{3}He	18 ℓ	9 ℓ	9 ℓ	4.5 ℓ
	^{4}He	72 ℓ	36 ℓ	36 ℓ	18 ℓ
low T container	^{3}He	10 ℓ	5 ℓ	5 ℓ	2.5 ℓ
	^{4}He	35 ℓ	17 ℓ	17 ℓ	8.5 ℓ



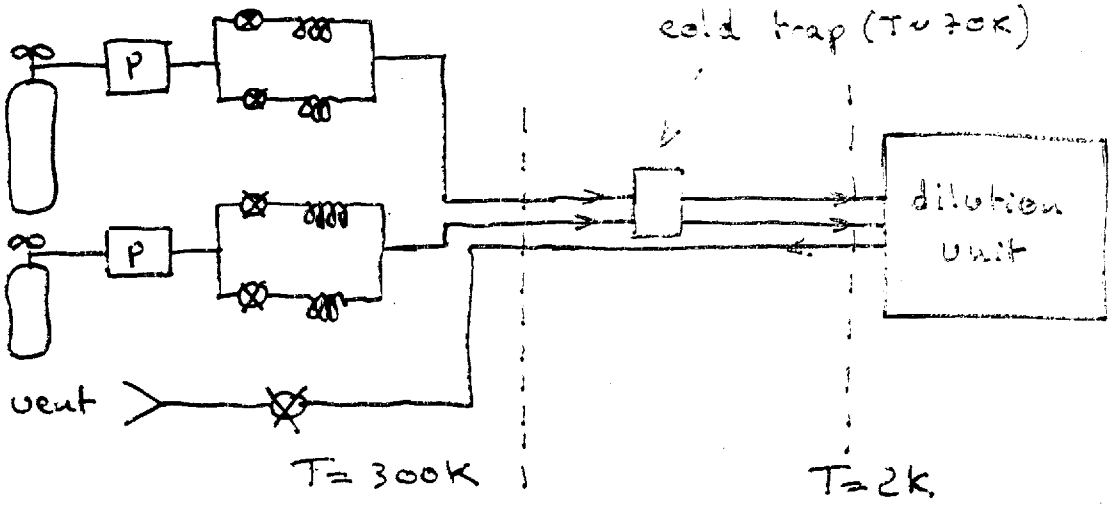
- control the pressure in container with the heater Q_1
  - → constant pressure ~ P ~ 3 bars
  - → temperature of container increases during the mission

  ^3He → 3K ... 5K ^4He → 5K 8K
- Measure of flow with heater Q_2
  - →

1) → same technique for ^3He and ^4He

2) → use a fountain pressure pump for ^4He
  - storage at T = 2K (constant temperature)
  - Liquid flow controlled with the pump heater

High temperature storage



$\boxed{P}$	pressure regulator input pressure $20b < P < 360b$ output pressure $P = 15b$
⊗	solenoide value
—ꝏ—	flow impedance (small capilliary)

Flow control with solenoide valves

input pressure decrease during the mission

cold trap and filters to avoid blocking

For space applications

Helium storage high or low temperature
→ tube connexions between 300K - 4K

precooling	Mechanical cooler	Helium cryostat			
Base temperature	4 K	4 K		2 K	
Helium storage temperature	300K	300K	4 K	300 K	2K
Large tube (φ 3)	1	1	1	0	0
small tube (φ 0.5 mm)	2	2	0	3	1

Only one small tube
from the cryostat to the ~~[illegible] stage~~ outer shell

→ no requirements { of heat exchangers
or cold traps
or filter