SPACE TELESCOPE SCIENCE INSTITUTE

3700 San Martin Drive
Baltimore, MD 21218
(410) 338-4700
FAX (410) 338-4767

Science Observatory Branch Report SOB-93-06-06

COSTAR Components added to the HST Instrument Graph for FOC, GHRS, and FOS

Keith Horne, George Hartig, Warren Hack, Calvin Tullos, Tony Keyes, David Soderblom

1993 Jun 6

SUMMARY

The HST instrument graph has been configured to include COSTAR's effect on the wavelength-dependent sensitivity for observations with the FOC, FOS, and HRS. There are 5 new tables giving the product of the reflectivity curves for each pair of COSTAR mirrors M1 and M2. There are also 17 new tables (2 for HRS and 15 for FOS) that give revised aperture throughputs as calculated at several wavelengths by using the TIM software to simulate the improved point-spread function that is expected to be produced by COSTAR.

The COSTAR effects on count rates can now be simulated with the synthetic photometry software packages XCAL and `iraf.stsdas.synphot`. To include the COSTAR components, just add the keyword `costar` to your usual `obsmode` parameter, e.g. `costar,fos,blue,g1601` . To omit the COSTAR components, add the keyword `nocostar`. For now, the `nocostar` option is the default, which means that COSTAR will be omitted unless you explicitly request it. However, after the refurbishment mission, it will make sense to change the HST instrument graph so that the default path includes the COSTAR components and the path omitting the COSTAR is taken only if `nocostar` is explicitly requested.

The sections below discuss for each instrument the changes made to include COSTAR in the HST instrument graph. Table 1 summarizes the new throughput tables with a key to the figures, which give plots of the new throughput curves adopted in each case.

Table 1. Key to COSTAR-related throughput tables

Component	Figure	Aperture
foc_48_m1m2	1	
foc_96_m1m2	1	
hrs_m1m2	2	
hrs_lsa_co	3	LSA
hrs_ssa_co	3	SSA
fos_blue_m1m2	4	
fos_red_m1m2	5	
fos_cir0p3_co	6	B-2
fos_cir0p5_co	6	B-1
fos_cir1p0_co	6	B-3
fos_sqr4p3_co	7	A-1
fos_sqr0p1l_co	7	A-4
fos_sqr0p25l_co	7	A-3
fos_sqr0p5l_co	7	A-2
fos_sqr1p0l_co	7	C-1
fos_sqr0p1u_co	7	A-4
fos_sqr0p25u_co	7	A-3
fos_sqr0p5u_co	7	A-2
fos_sqr1p0u_co	7	C-1
fos_0p25x2p0_co	8	C-2
fos_0p7x2p0bar_co	8	C-4
fos_2p0bar_co	8	C-3

1 COSTAR components for the FOC

COSTAR has separate pairs of mirrors to correct the FOC F/48 and F/96 cameras trains, and accordingly the HST instrument graph uses different component names and throughput tables, foc_48_m1m2 and foc_96_m1m2, to allow for possibly different reflectivity curves. Since FOC is an imaging instrument, there are no aperture throughput tables to revise.

For the FOC, the COSTAR components are included in the HST instrument graph table as follows :

```
_____COMPNAME_____ __KEYWORD___ __INNODE__ _OUTNODE__
clear              foc            30        2000
clear              f/48          2000       2005
clear              spec          2000       2005
foc_48_m1m2        costar        2005       2010
clear              nocostar      2005       2010
clear              default       2005       2010
```

clear	f/96	2000	2500
clear	f/288	2000	2500
foc_96_m1m2	costar	2500	2505
clear	nocostar	2500	2505
clear	default	2500	2505

Keyword `foc` selects a path to the FOC nodes, which are numbered 2000 through 2999. From node 2000, keywords `f/48` or `spec` select the path to node 2005. From node 2005 the keywords `costar` or `nocostar` select alternative paths from to node 2010. The `nocostar` path is clear (i.e. throughput of 1 at all wavelengths) while the `costar` path includes the component `foc_48_m1m2`, which gives the product of the reflectivity of the two COSTAR mirrors FOC F/48 M1 and M2. The default path is `nocostar`.

Similarly, the keywords `f/96` and `f/228` each choose the path from node 2000 to node 2500, and from node 2500 the keywords `costar` or `nocostar` choose to include or omit the `foc_96_m1m2` component in passing to node 2505. In this case as well `nocostar` is the default path.

The reflectivity curves adopted at the present time are identical, as plotted in Figure 1. These reflectivities are from laboratory measurements at GSFC of the witness mirrors that were aluminized in the same batch as the flight mirrors. The COSTAR components for the FOC were installed in CDBS by Warren Hack and Calvin Tullos.

2 COSTAR components for the GHRS

GHRS has two apertures, LSA and SSA, but they are so close together in the focal plane of the HST that COSTAR employs a single pair of mirrors to correct the point-spread function for both apertures. The improved point-spread function means that a larger fraction of the light enters the apertures, so new aperture throughput tables are needed for the post-COSTAR era.

For the GHRS, the COSTAR components are included in the HST instrument graph table as follows :

-----COMPNAME-----	--KEYWORD---	--INNODE--	-OUTNODE--
clear	hrs	30	6000
clear	nocostar	6000	6010
clear	default	6000	6010
hrs_ssa	ssa	6010	6100
hrs_lsa	lsa	6010	6100
hrs_m1m2	costar	6000	6060
hrs_ssa_co	ssa	6060	6100
hrs_lsa_co	lsa	6060	6100

Keyword hrs selects a path to the HRS nodes numbered 6000 through 6999. From node 6000, keyword nocostar moves to node 6010 with component clear (i.e. throughput of 1 at all wavelengths). This is the default path. From node 6010 to node 6100, the keywords ssa and lsa select components hrs_ssa and hrs_lsa respectively, which are the pre-COSTAR aperture throughputs.

Keyword costar selects the path from node 6000 to node 6060, picking up the component hrs_m1m2 which gives the product of the reflectivity curves of the two COSTAR mirrors GHRS M1 and M2. The path from node 6060 to node 6100 is selected by the keywords ssa and lsa, which choose between the components hrs_ssa_co and hrs_lsa_co which give the post-COSTAR throughput curves of the two apertures taking into account the improved point-spread function.

Figure 2 plots the adopted reflectivity curve for hrs_m1m2. The reflectivity curve is taken from laboratory measurements made at GSFC of COSTAR witness mirrors and is the product of the reflectivities of the two mirrors M1 and M2.

Figure 3 plots the adopted aperture throughput curves for hrs_lsa_co and hrs_ssa_co. The upper and lower curves in Figure 3 give as functions of wavelength the fraction of the light from the post-COSTAR point-spread function that gets through the two GHRS apertures LSA and SSA respectively. The GHRS aperture throughputs for the LSA and SSA as currently installed in the database are rough estimates that may be improved upon later. For the SSA (0.25 arcsecond square) we adopt a throughput curve identical to that of the 0.25 arcsecond square FOS aperture. For the LSA (2.0 arcsecond square) we interpolate between the throughput curves of the FOS 4.3 and 1.0 arcsecond square apertures. As discussed below, the FOS aperture throughput curves were calculated by using the TIM software to model the post-COSTAR point-spread function for selected wavelengths at the FOS aperture position. Since the sizes and effective locations of the GHRS and FOS apertures are similar, these should be adequate approximations for use in estimating rough count rates and exposure times. The database will be updated in the post-COSTAR era to improve the agreement between predicted and observed counts with the GHRS.

Bear in mind that GHRS is an ultraviolet spectrograph, thus only the spectral region 1000-3300Å is relevant for simulations of GHRS observations. The wider wavelength range shown in Figures 3 and 4 is intended here to document the full contents of the database and for ease of comparison with the other instruments.

3 COSTAR components for the FOS

The FOS is like the GHRS in that both the reflectivities of the COSTAR mirrors and new aperture throughputs are needed. The COSTAR uses separate pairs of mirrors to correct the light paths to the the FOS RED and BLUE detectors, and on each path there are 15 possible apertures.

For the FOS the COSTAR components are included in the HST instrument graph table as follows :

_____COMPNAME_____	__KEYWORD___	__INNODE__	_OUTNODE__
clear	fos	30	1000
clear	red	1000	1501
clear	blue	1000	1001
clear	nocostar	1001	1002
clear	default	1001	1002
fos_blue_m1m2	costar	1001	1005
clear	default	1002	1010
fos_cir0p3	0.3	1002	1010
fos_cir0p5	0.5	1002	1010
fos_cir1p0	1.0	1002	1010
clear	upper	1002	1003
fos_sqr0p1u	0.1-pair	1003	1010
fos_sqr0p25u	0.25-pair	1003	1010
fos_sqr0p5u	0.5-pair	1003	1010
fos_sqr1p0u	1.0-pair	1003	1010
fos_sqr0p5u	failsafe	1003	1010
clear	lower	1002	1004
fos_sqr0p1l	0.1-pair	1004	1010
fos_sqr0p25l	0.25-pair	1004	1010
fos_sqr0p5l	0.5-pair	1004	1010
fos_sqr1p0l	1.0-pair	1004	1010
fos_sqr4p3	failsafe	1004	1010
fos_0p25x2p0	0.25x2.0	1002	1010
fos_0p7x2p0bar0p3	0.7x2.0-bar	1002	1010
fos_sqr2p0bar0p3	2.0-bar	1002	1010
fos_sqr4p3	4.3	1002	1010
dark	blank	1002	1010
clear	default	1006	1010
fos_cir0p3_co	0.3	1006	1010
fos_cir0p5_co	0.5	1006	1010
fos_cir1p0_co	1.0	1006	1010
clear	upper	1006	1007
fos_sqr0p1u_co	0.1-pair	1007	1010
fos_sqr0p25u_co	0.25-pair	1007	1010
fos_sqr0p5u_co	0.5-pair	1007	1010
fos_sqr1p0u_co	1.0-pair	1007	1010
fos_sqr0p5u_co	failsafe	1007	1010

clear	lower	1006	1008
fos_sqr0p1l_co	0.1-pair	1008	1010
fos_sqr0p25l_co	0.25-pair	1008	1010
fos_sqr0p5l_co	0.5-pair	1008	1010
fos_sqr1p0l_co	1.0-pair	1008	1010
fos_sqr4p3_co	failsafe	1008	1010
fos_0p25x2p0_co	0.25x2.0	1006	1010
fos_0p7x2p0bar_co	0.7x2.0-bar	1006	1010
fos_sqr2p0bar_co	2.0-bar	1006	1010
fos_sqr4p3_co	4.3	1006	1010
dark	blank	1006	1010

Keyword `fos` selects a path to the FOS nodes numbered 1000 through 1999. Keywords `red` and `blue` select paths to nodes 1001 and 1501 respectively. From node 1001 the path leads to node 1002 with keyword `nocostar` or 1006 with keyword `costar` . Paths from node 1001 to 1010 include the pre-COSTAR aperture throughtputs, while paths from node 1006 to 1010 include the post-COSTAR aperture throughputs. The graph looks complicated because FOS has so many apertures.

A similar graph structure is used for the FOS RED paths from node 1501 to node 1510 :

_____COMPNAME_____	__KEYWORD___	__INNODE__	_OUTNODE__
clear	nocostar	1501	1502
clear	default	1501	1502
fos_red_m1m2	costar	1501	1506
clear	default	1502	1510
fos_cir0p3	0.3	1502	1510
fos_cir0p5	0.5	1502	1510
fos_cir1p0	1.0	1502	1510
clear	upper	1502	1503
clear	lower	1502	1504
fos_sqr0p1u	0.1-pair	1503	1510
fos_sqr0p25u	0.25-pair	1503	1510
fos_sqr0p5u	0.5-pair	1503	1510
fos_sqr1p0u	1.0-pair	1503	1510
fos_sqr0p5u	failsafe	1503	1510
fos_sqr0p1l	0.1-pair	1504	1510
fos_sqr0p25l	0.25-pair	1504	1510
fos_sqr0p5l	0.5-pair	1504	1510
fos_sqr1p0l	1.0-pair	1504	1510
fos_sqr4p3	failsafe	1504	1510
fos_0p25x2p0	0.25x2.0	1502	1510
fos_0p7x2p0bar0p3	0.7x2.0-bar	1502	1510

fos_sqr2p0bar0p3	2.0-bar	1502	1510
fos_sqr4p3	4.3	1502	1510
dark	blank	1502	1510
clear	default	1506	1510
fos_cir0p3_co	0.3	1506	1510
fos_cir0p5_co	0.5	1506	1510
fos_cir1p0_co	1.0	1506	1510
clear	upper	1506	1507
clear	lower	1506	1508
fos_sqr0p1u_co	0.1-pair	1507	1510
fos_sqr0p25u_co	0.25-pair	1507	1510
fos_sqr0p5u_co	0.5-pair	1507	1510
fos_sqr1p0u_co	1.0-pair	1507	1510
fos_sqr0p5u_co	failsafe	1507	1510
fos_sqr0p1l_co	0.1-pair	1508	1510
fos_sqr0p25l_co	0.25-pair	1508	1510
fos_sqr0p5l_co	0.5-pair	1508	1510
fos_sqr1p0l_co	1.0-pair	1508	1510
fos_sqr4p3_co	failsafe	1508	1510
fos_0p25x2p0_co	0.25x2.0	1506	1510
fos_0p7x2p0bar_co	0.7x2.0-bar	1506	1510
fos_sqr2p0bar_co	2.0-bar	1506	1510
fos_sqr4p3_co	4.3	1506	1510
dark	blank	1506	1510

To summarize for the FOS we have 2 new throughput tables `fos_blue_m1m2` and `fos_red_m1m2` that give the product of the reflectivities of the two COSTAR mirrors M1 and M2 for the blue and red paths respectively. Figure 4 shows the `fos_blue_m1m2` reflectivity curve, which is similar to those for the FOC and GHRS (Figures 1 and 2). Figure 5 shows the `fos_red_m1m2` reflectivity curve, which is somewhat different from the other curves.

For the FOS there are 15 new throughput tables that give revised aperture throughput functions taking into account the improved point-spread function to be produced by COSTAR. The post-COSTAR aperture throughputs are distinguished from their pre-COSTAR counterparts by adding the suffix `_co` to the component name. For example, the old 1.0 arcsecond circular aperture is referred to as `fos_cir1p0_co`. Take note, however, that the COSTAR mirrors magnify the focal plane by a factor of roughly 1.16 and this decreases the post-COSTAR aperture dimensions by a factor of roughly 0.86.

George Hartig used the TIM (Telescope Instrument Modelling) software to compute the post-COSTAR point-spread function for the location of the FOS aperture in the HST focal plane at wavelengths 1500, 2250, 3400, 5000, 7500, and 9000Å, and integrated the point-spread functions over each FOS aperture to determine the fraction of light entering the aperture for each of these wavelengths. Our synthetic photometry software uses a linear interpolation to derive throughputs at intermediate wavelengths. A linear extrapolation was used to extend the wavelength coverage of the throughput tables to 1000Å and to 12000Å beyond which a constant extrapolation is used.

The throughput curves for the FOS's 1.0, 0.5, and 0.3 arcsecond diameter circular apertures are plotted in Figure 6. These aperture throughput curves give as functions of wavelength the fraction of the light from the post-COSTAR point-spread function that passes through the appropriate aperture. Figure 7 gives the throughput curve for the 4.3 arcsecond square aperture along with those for the upper members of the paired 1.0, 0.5, 0.25, and 0.1 arcsecond square apertures. The lower and upper members of the paired are treated as separate components in the database but are currently assigned identical throughput curves. Figure 8 plots the throughput curve for `fos_0p25x2p0_co`, which is the 0.25 x 2.0 arcsecond slit, and the throughput curves for point sources located directly behind the occulting bars of the wide and narrow occulting apertures, `fos_2p0bar_co` and `fos_0p7x2p0bar_co` respectively. In the latter cases the aperture throughput is low indicating that roughly 85 to 90 percent of the light from the star is blocked by the occulting bar.

The HST instrument graph currently assumes that the aperture throughput functions are the same for the FOS BLUE and RED light paths. Since the apertures are at different locations in the HST focal plane, the COSTAR optics should produce slightly different point-spread functions and hence aperture throughputs for the RED and BLUE paths. This small difference can be taken into account after FOS data has been obtained and analyzed in the post-COSTAR era by updating the throughput tables (e.g. `fos_g130h_r`) that give fudge factors for each grating-detector combination.

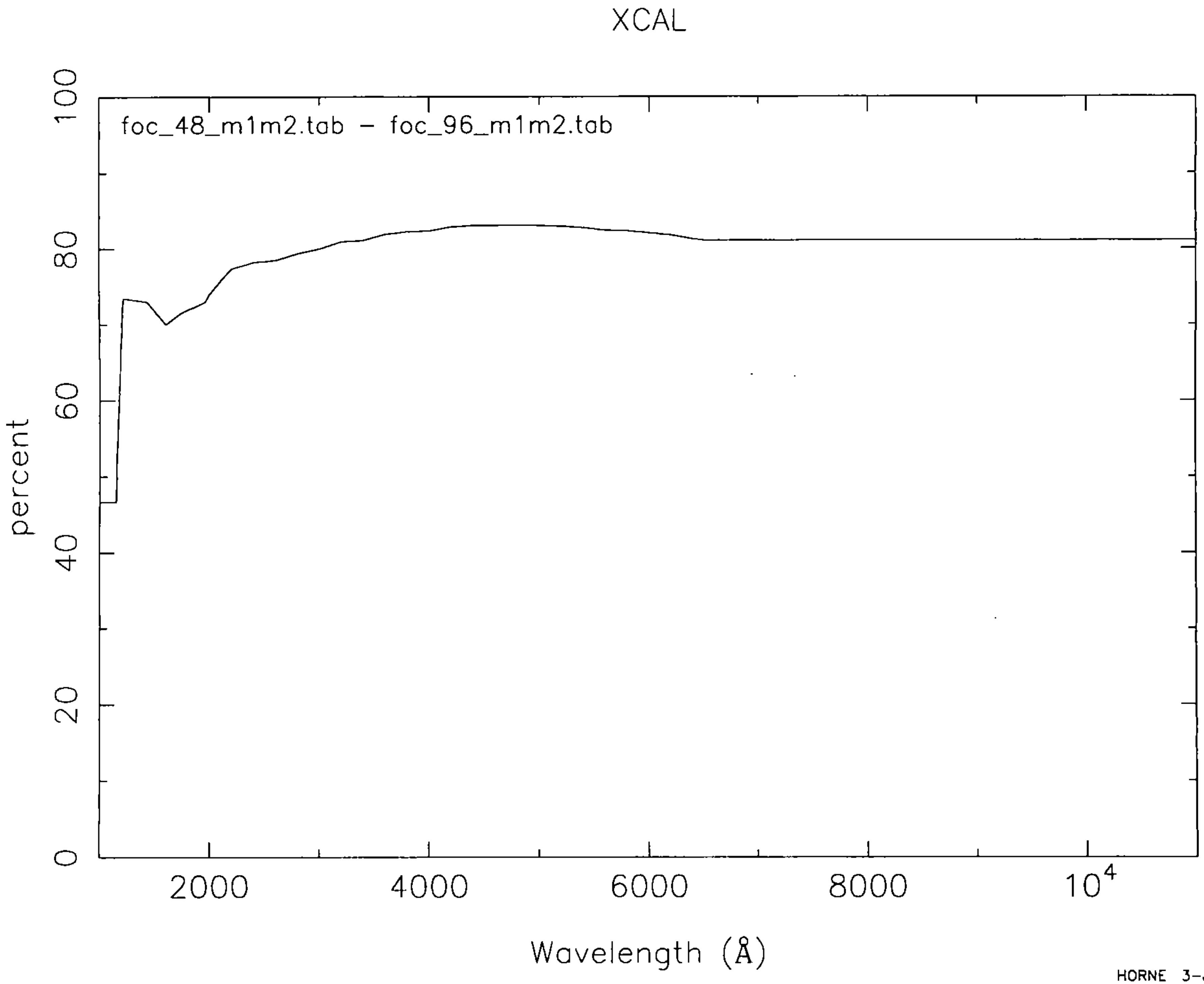

FIG 1

HORNE 3-JUN-1993 18:45

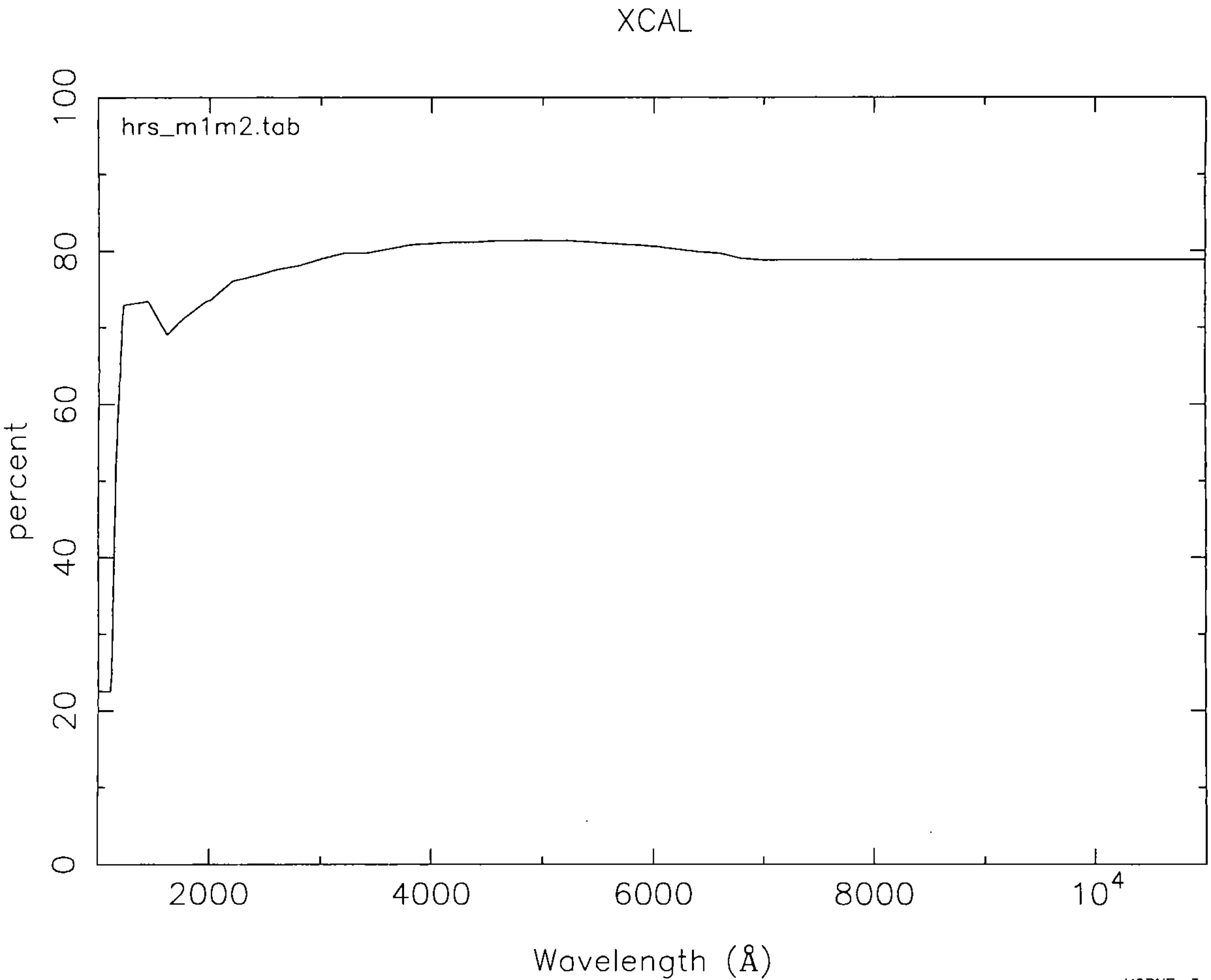

FIG 2

HORNE 3-JUN-1993 18:45

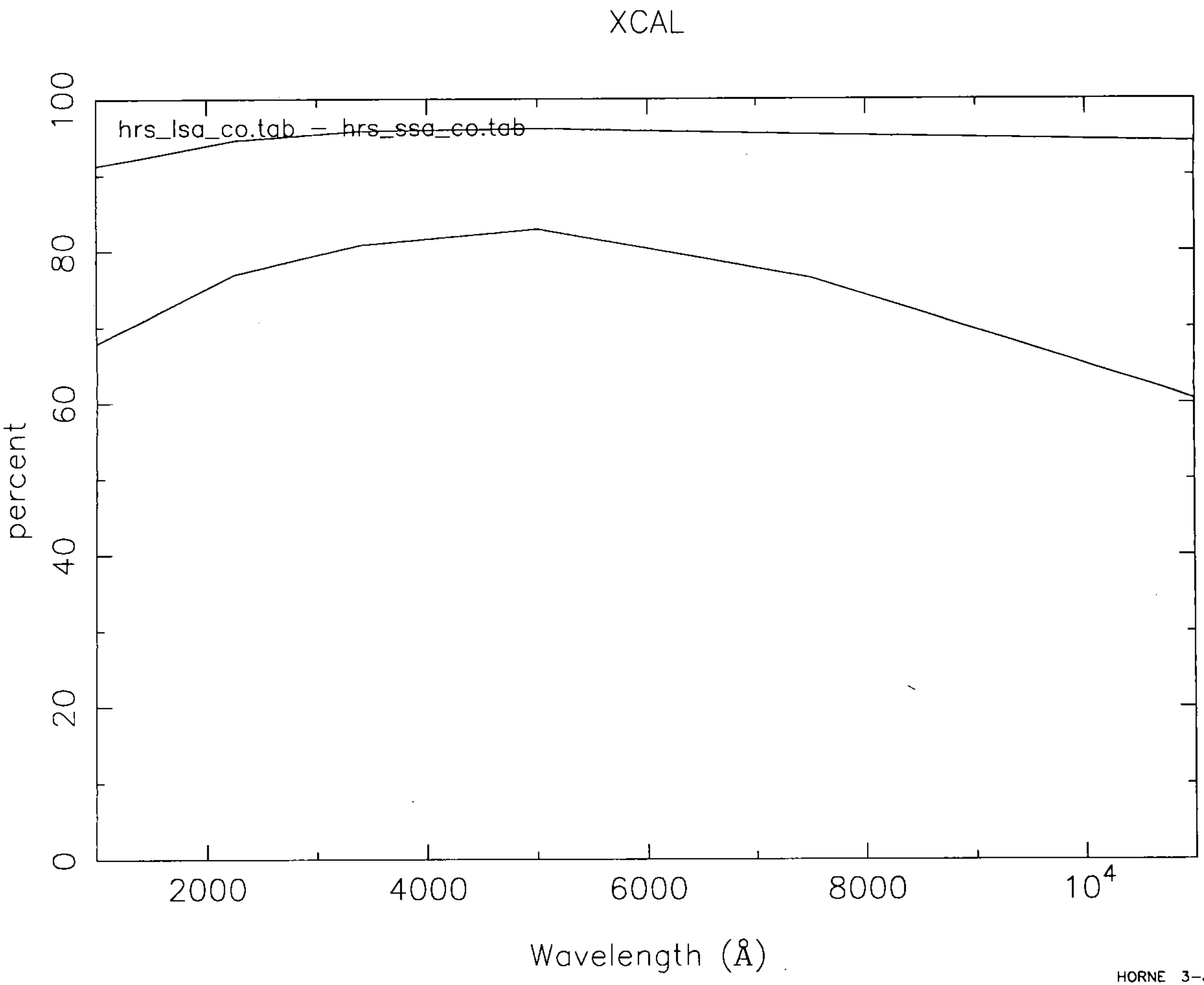

FIG 3

HORNE 3-JUN-1993 18:45

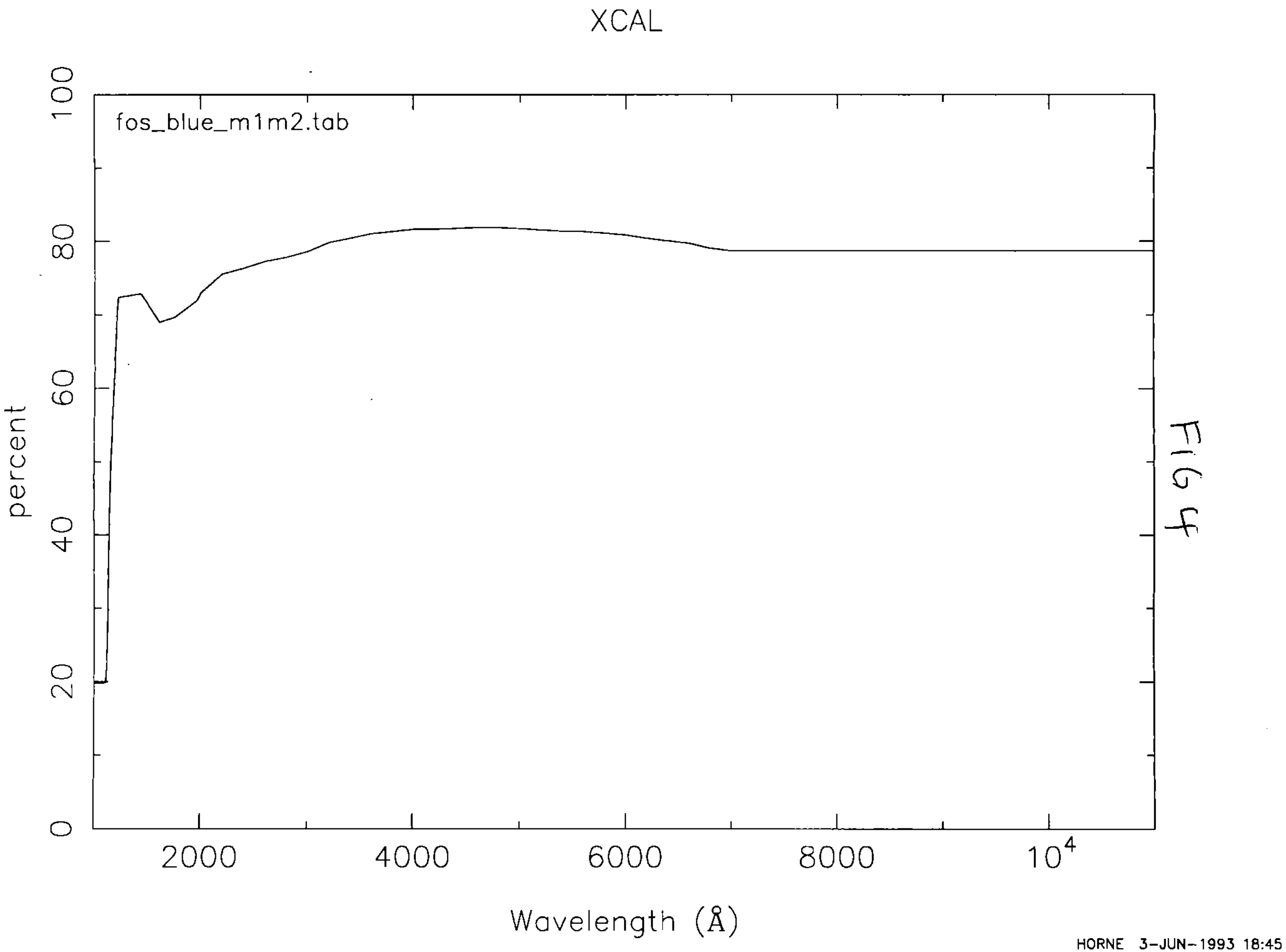
XCAL
fos_blue_m1m2.tab
percent
0
20
40
60
80
100
2000
4000
6000
8000
10^4
Wavelength (Å)
HORNE 3-JUN-1993 18:45

FIG 4

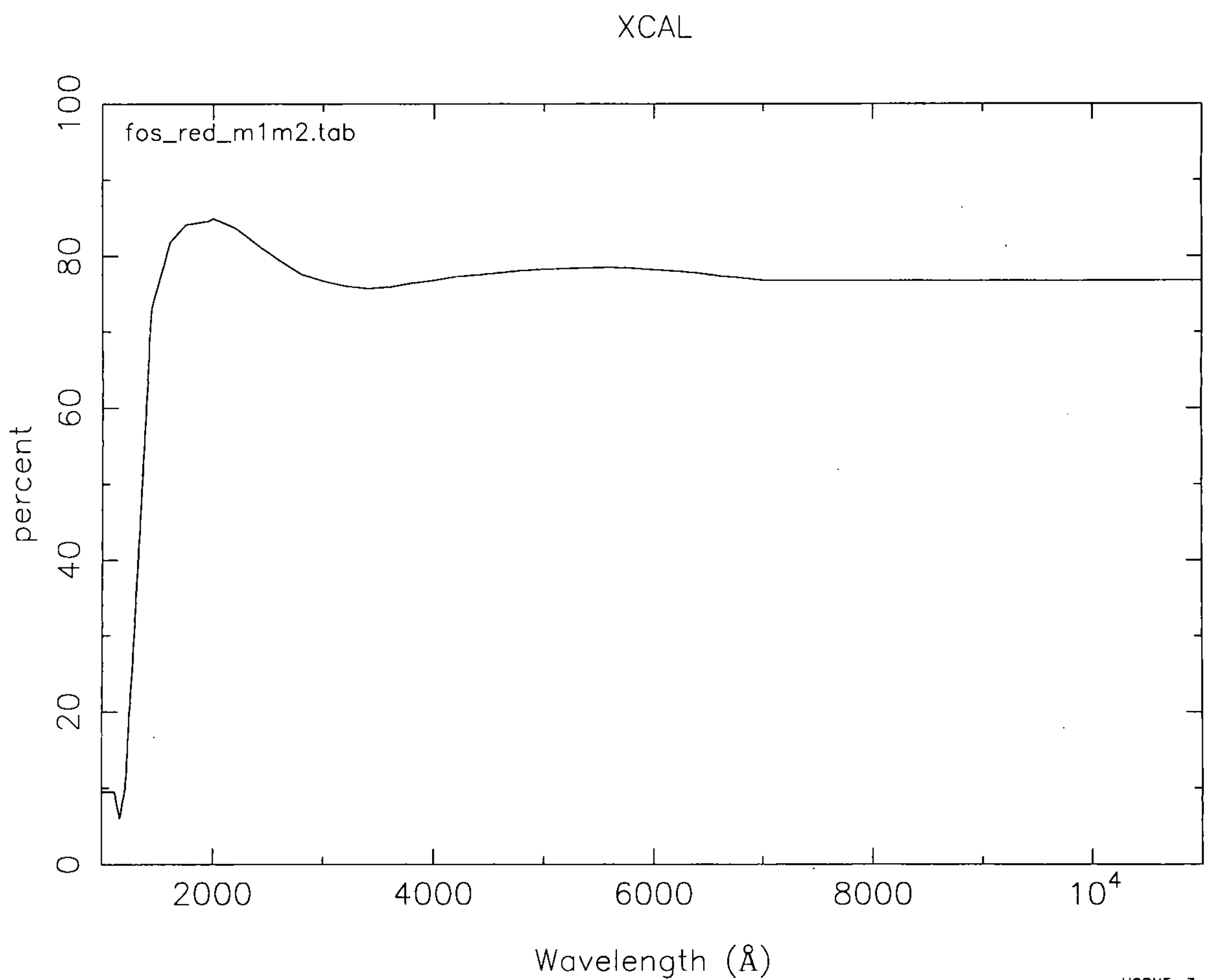

FIG 5

HORNE 3-JUN-1993 18:45

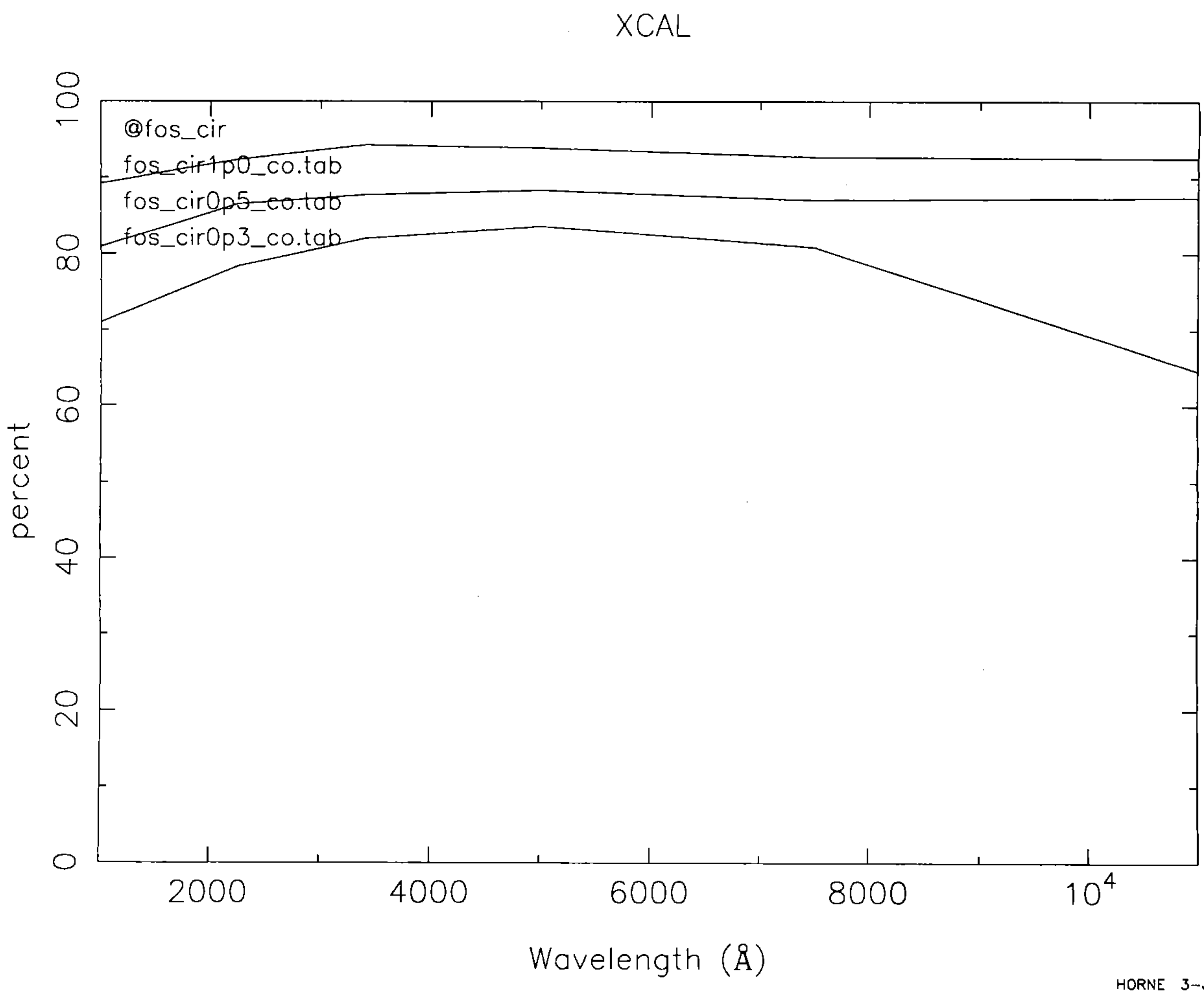

FIG 6

HORNE 3-JUN-1993 18:45

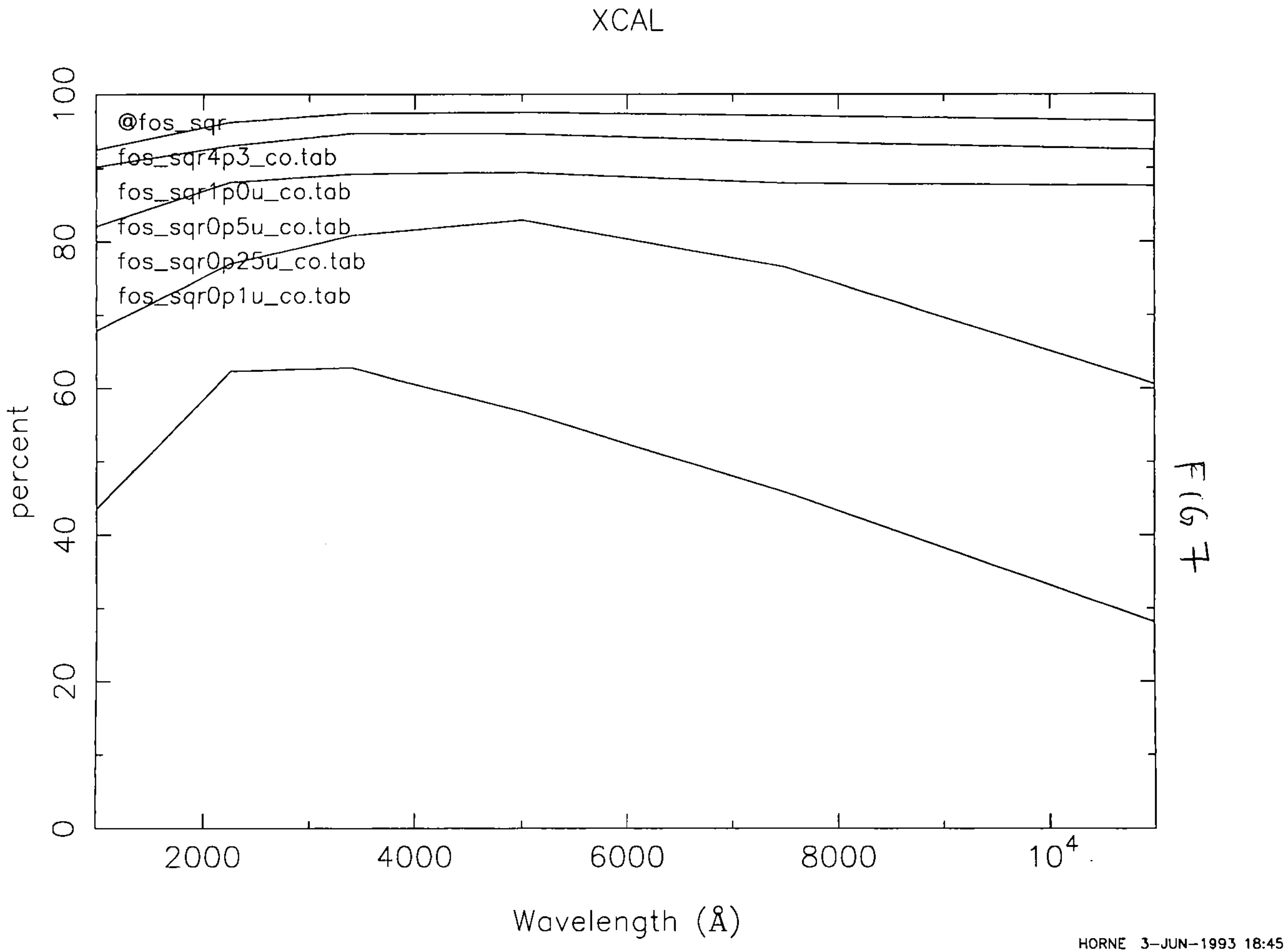
XCAL
@fos_sqr
fos_sqr4p3_co.tab
fos_sqr1p0u_co.tab
fos_sqr0p5u_co.tab
fos_sqr0p25u_co.tab
fos_sqr0p1u_co.tab
percent
0
20
40
60
80
100
2000
4000
6000
8000
10^4
Wavelength (Å)
HORNE 3-JUN-1993 18:45

FIG 7

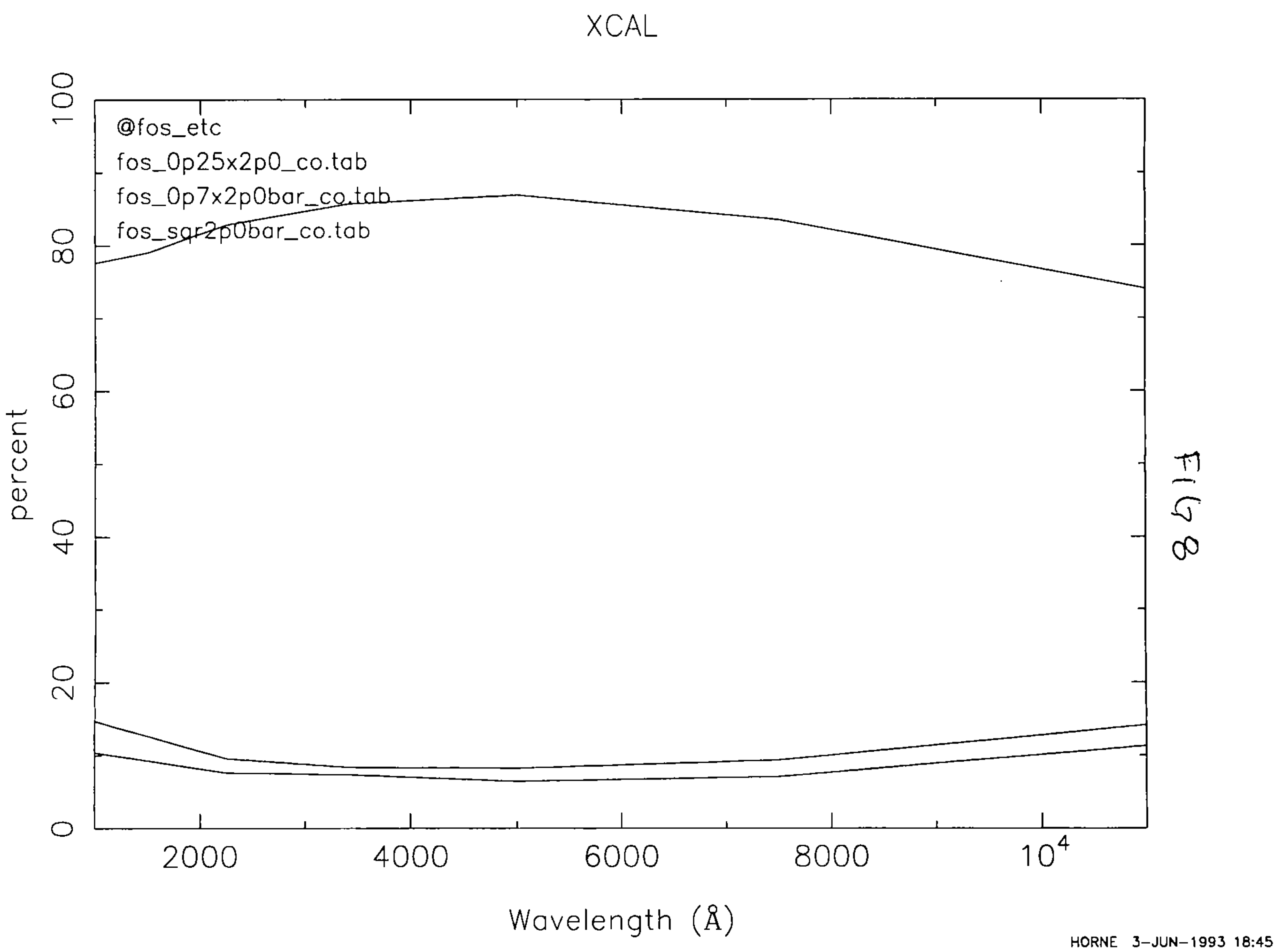
XCAL
@fos_etc
fos_0p25x2p0_co.tab
fos_0p7x2p0bar_co.tab
fos_sqr2p0bar_co.tab
percent
0
20
40
60
80
100
2000
4000
6000
8000
10^4
Wavelength (Å)
HORNE 3-JUN-1993 18:45

FIG 8