



TO: Distribution DATE: 16 May 1986

FROM: Roland Buser, Keith Horne and Jan Koornneef

SUBJECT: GRIDS OF STELLAR AND NON-STELLAR FLUX DISTRIBUTIONS

The generation of absolute flux distributions for all photometric and spectrophotometric calibration targets requires, in addition to observational data and throughput functions, access to catalogues of observed and model flux distributions.

Section I of the present memo provides an inventory of potentially relevant material with emphasis on spectrophotometric data-sets. We indicate the characteristics of the various catalogues and, in many cases, comment briefly on their potential uses. Several data-sets are already available at the STScI and their status in this respect, when known, is also given. Some of the catalogues being brought in for calibration purposes are of sufficient general interest to be included in the Institute's 'On-Line Astronomical Catalogue Utility', the generation of which Dave Soderblom has generously offered to take on.

In Section II we provide a first-draft-level proposal to construct a grid of well over a hundred flux distributions, representative for a wide variety of astronomical sources, patched together from a subset of current catalogues. The proposal is to cover the whole wavelength range of HST (1200-12000A) with the fluxes renormalized, as necessary, to conform to generic intrinsic photometric colours and zero visual magnitude. The grid will find multiple uses in the calibration effort but an attempt was made to also make it useful as a primary source of spectrophotometric 'stimuli' for use in instrument simulators and exposure calculators.

Finally, we include as Section III a proposal by one of us (RB) to construct a more ambitious set of stellar energy distributions. This section also provides a historical background for the work on grids in general. While still geared towards the needs of HST, Buser's upcoming results should provide help for problems requiring a larger and intrinsically more homogeneous data-set than the default grid mentioned above, especially in the area of Pop II objects and their relation to Pop I.

Distribution:

ISB all

CDBS (W. Pence ; 5 copies)

SDAS (B. Hanish ; 5 copies)

PEPSI (M. Johnston ; 5 copies)

CSC (C.-C. Wu; 5 copies)

RSB D. Soderblom

Section I: An inventory of spectrophotometric catalogues

The generation of absolute flux distributions for all photometric and spectrophotometric calibration targets requires, as explained elsewhere, access to catalogues of observed and model flux distributions.

Briefly, data from the catalogues will be used to 'patch' wavelength regions where observational data are missing such as in the atmospheric gap between the (IUE-) ultraviolet and the optical regimes. Also, the responsivity of the CCDs on HST goes beyond where reliable ground-based observations are available and stellar-model data will therefore be needed. The most extreme patching will occur for those photometric calibration targets for which only photometric data are available. In those cases, a suitable flux distribution will be taken from the libraries, followed by a renormalization process constrained by the photometric observations.

The availability of the catalogues will certainly encourage multiple uses. Obvious examples include the computation of synthetic colours for a given (HST-) filter set. An observer can use such results to directly compare his observations with the range in astrophysical parameters covered by the library he adopted (e.g. gravity, metallicity, effective temperature). Some of this type of work will be desirable even before launch as there exist concerns with respect to the suitability of the proposed WFPC Population II Calibration Targets for the calibration of Population I science targets. Note that the libraries, while possibly intrinsically homogeneous on an individual basis, have wildly varying pedigrees and intercomparison of results based on multiple libraries requires extreme caution. The proposals of Sections II and III of the present memo can both be regarded as attempts to merge a number of relevant source-catalogues into a homogeneous data-set. Section II describes a default grid which leans heavily on work previously done at the STScI and can therefore be finalized at short notice, whereas the proposal of Section III is both more ambitious and time consuming.

In the four tables attached to the present Section, we provide an inventory of relevant material i.e., catalogues of immediate interest. We indicate the characteristics of the various catalogues and, in many cases, comment briefly on their potential uses. Several data-sets are already available at the STScI and their status in this respect, when known, is also given. In particular, we mention the implementation of several high priority data-sets in binary form in the ATLAS account on KEPLER. Using the routines LOADATLAS and EVALATLAS, these libraries can now be attached to the synthetic photometry package described elsewhere.

TABLE 1

ATLASES OF OBSERVED STELLAR ENERGY DISTRIBUTIONS

Atlas Name	Source Reference	Types	Number	Wavelength (\AA)	Resolution	Comments	Status
GS	Gunn & Stryker 1983	PI/O-M/I,III,V	175	3,130-10,800	20/40	*	1
JHC	Jacoby <i>et al.</i> 1984	PI/O-M/I,II,III,V	161	3,510-7,427	\sim 4.5	*	2
CH	Christensen 1978	PII/SG,G,HB	65	3,448-10,800	160	*	3
WDO	Oke 1974	WD	10	3,200-10,500	10/.../160	*	3
UCH	Cacciari 1985	PII/SG,G,HB	36	1,150-3,200	5	*	2
UWD	(ST ScI)	WD + sdO	9	1,150-3,200	2	*	2
UNA	Wu <i>et al.</i> 1981	PI/O-M/I-V	173	1,150-3,200	5	*	2
UES	Heck <i>et al.</i> 1984	PI/O-K/I-V	229	1,150-3,200	5	*	2

Status: 1---implemented final

2---implemented in original form

3---in process

4---tabular

5---tape

TABLE 2
ATLASES OF THEORETICAL STELLAR ENERGY DISTRIBUTIONS

Atlas Name	Source Reference	Types/Parameters	Number	Wavelengths (Å)	Flux Points	Comments	Status
K1200	Kurucz 1979	Early all/T 5,500-50,000 G 0-5	1200	229-200,000	342	†	2
BKGBEN	Buser & Kurucz 1985	Late all/T 3,750-6000 A 1 (-9.99) G 0.75-5.25	242	229-200,000	342	†	2
WES	Wesemael <i>et al.</i> 1980	WD+sdO ₂ B/T 20,000-300,000 A 0-(-3) G 4-9	78	103-300,000	157	†	2
TM	Terashita & Matsushina 1969	WD/T 7,000-25,000 A pure H G 6-9	15	3000-12,200	65	†	2
SC	Shipman 1977	WD/T 4000-8,000 A pure H G 7-8	8	3156-19,095	15	†	1
SH	Shipman 1971	HB/T 15,000-25,000 A pure H G 5-6 A 1	10	3,000-12,000	15/27	†	1

Status: 1 -- implemented final

2 -- implemented in original form

3 -- in process

4 -- tabular

5 -- tape

TABLE 3

ATLASSES OF HYBRID STELLAR ENERGY DISTRIBUTIONS

Atlas Name	Source Reference	Types	Number	Wavelength (Å)	Resolution	Comments	Status
KB	King & Bruzual 1985	F1/O-M/I,III,V	77	240-10,000	20/50	*	1
BI	Bruzual 1980	F1/O-M/I,III,V	54	240-34,000	20/50	*	2
SS	Straižys & Sviderskiene 1972	F1/O-M/I,III,IV,V	49	3,000-10,000	50	*	2
IJ	ST ScI: FOS	F1/O-M/I,III,V	55	1,150-7,427	5	*	2

Status: 1 --implemented final

2 --implemented in original form

3 --in process

4 --tabular

5 --tape

TABLE 4

ATLASES OF NON-STELLAR ENERGY DISTRIBUTIONS

Atlas	Source Reference	Types	Number	Wavelength (Å)	Resolution	Nature	Comments	Status
PICG	Pickles & Visvanathan 1985	Galaxies/E,S0	20	3,605-8,849/9,989	12	OBS	†	5
BGM	Bruzual 1980	Galaxies/models	118	240-34,000	20/50	MOD	†	2
COL	Coleman <i>et al.</i> 1980	Galaxies/E,Sbc,Scd,IM	5	1,400-10,000	100/40/100	HYB	†	4
PN	ST ScI FWSIMLIB	Planetary Nebula	1	3,400-9,000	0.5	HYB	†	2
QSO	ST ScI FWSIMLIB	QSO	1	300-12,000	20/.../500	HYB	†	2

Status: 1—implemented final

2—implemented in original form

3—in process

4—tabular

5—tape

Section II: A proposal for a default grid of spectrophotometric 'stimuli'

In their recent paper on 'Synthetic Photometry and the Calibration of the Hubble Space Telescope, Koornneef *et al.* (1986) choose to illustrate the power and usefulness of synthetic photometry by constructing synthetic two-colour diagrams for the 'UBV analogous' systems on HST as well as for the Johnson UBV system. They combined representative passbands with the library of 49 stellar flux distributions of Straižys and Sviderskiene (1972). This particular library was selected because it was readily available, well documented and has proven itself in this type of work (e.g. Buser, 1978). The Straižys library runs from 3000 to 10000 Å (resolution 50 Å) and is hybrid in the sense that each flux distribution has been constructed from observations of different stars of similar spectral type, as well as appropriate model atmospheres.

Ivan King, in his efforts to understand the photometric properties of both the FOC and WFPC 'workhorse' filters is using a version of an unpublished set of 77 stellar flux distributions based on the Kurucz models and on a grid due to Bruzual. King produced (priv. comm. March 4, 1985) many two colour diagrams, some of which are similar to the ones shown in Koornneef *et al.* (1986). They cannot, however, be directly intercompared as—apart from the throughput functions—the relationship between the Straižys and King grids are not yet known. King's grid is available at the STScI and is accessible from the FOC/WFPC simulator.

In search of a good set of spectrophotometric stimuli for the FOS simulator, Holland Ford took advantage of work by Robin Ciardullo who, assisted by Claudia Testa, constructed a hybrid stellar grid using the Jacoby *et al.* (1984) optical scans, IUE observations in the ultraviolet and the King grid in the 'middle'. The resulting grid is well matched to the FOS resolution and goes as red as 7425 Å, which is more than adequate for the present FOS wavelength coverage. This grid is also available with the HSP simulator.

We suggest that for all of the above applications it would be important to have access to a common, or default, grid. In trying to make everybody happy, one runs the risk,

of course, to make everybody a little unhappy. After some consideration, we nevertheless venture to suggest the compromise summarized on the following page. Note that the type of work needed to generate and document the 'default grid' is virtually identical to the work involved in generating flux distributions for calibration targets.

As suggested before, we would normalize all energy distributions to zero visual magnitude. The documentation of the default grid therefore should include a table with absolute visual magnitudes for all objects for which that makes sense (not: black bodies etc.; how to deal with extended sources such as HII regions ?).

a) Population I stellar sources

The Jacoby *et al.* catalogue is the only optical spectral atlas with sufficient spectral resolution to meet the needs of the FOS. Our own study of this catalogue shows that its photometric quality as well as its associated astrophysical information (like the spectral types) needs to be more fully checked. Nolan Walborn has provided some changes in the spectral types for the hottest stars and suggested that a few stars should be deleted because of extreme peculiarity. There is presently only limited documentation on how Robin Ciardullo and Claudia Testa have actually combined the Jacoby flux distributions with the King model grid and the IUE spectra, but such information is forthcoming (Holland Ford, priv. comm.). Barring unexpected surprises, we suggest that the 55 Ciardullo/Testa distributions are extended in the red with the King spectra, to be followed by a renormalization in order to make them conform to generic intrinsic (ANS-) ultraviolet and (Johnson-Cousins) UBVRI observed data.

The distribution of the Jacoby stars over the HR diagram needs to be checked and we might choose to fill some gaps with a subset of the Bruzual grid, renormalized in the same manner. The total number of Pop I stars would then be in the order of seventy or eighty.

b) Population II stellar sources

As a large percentage of the HST science targets (and quite a few of the calibration targets !) will be Pop II, this category requires further attention. None of the grids mentioned on the previous page include any Pop II sources. We have asked for inputs from Pop II (IUE-) observers (in particular Carla Cacciari and Klaas de Boer), who feel that the UV observational situation is rather difficult to evaluate, but that there is hope for rapid development. However, we have made available, in advance of publication, a comprehensive grid of theoretical model atmosphere flux distributions constructed by Kurucz and by Buser and Kurucz, which excellently reproduce the optical and near-IR colors for a wide range of observed population II stars.

We propose to generate, by interpolation from the full grid, 20 metal-poor ($[M/H] = -2$) models with effective temperatures and gravities corresponding to the 16 billion year isochrone representative of a galactic globular cluster. These 20 models can then be used to calculate the differential colors relative to their population I ($[M/H] = 0$) model counterparts, and results can be applied to the default grid population I spectra to generate the default grid population II flux distributions.

c) High gravity stars

A large part of the spectrophotometric standards, selected because of their relatively featureless spectra, are either WD, sdO or sDB. We think that the default grid should include some energy distributions representative for these spectral types. In this category, the correspondence between the models and the observations is excellent, and we propose the inclusion of about ten flux distributions patched together from the IUE observations, from optical observations by Oke and the Wesemael *et al.* models. Some renormalization of the continua is required to conform to generic intrinsic colours.

In conclusion, the stellar part of the default grid could be constructed from the following catalogues, which are all available on the ATLAS account:

ATLAS	NATURE	SOURCES	OBJECTS	##	WAVE-LENGTHS	STATUS
IJ (FOS+HSP)	Hybrid	Jacoby <i>et al.</i>	Pop I O-M,I-V	55	1200-7425	old
		IUE Kurucz	WD	17	1155-3345	
KB (FOC+WFPC)	Hybrid	Kurucz-Bruzual	Pop I O-M, I,III,V	77	240-10,000	old
BKGBEN/ K1200	Models	Buser-Kurucz/ Kurucz	Pop II HB,sd,sg,g	400	1,200-12,000	new
WDO/UWD WES	OBS Models	Oke/IUE Wesemael <i>et al.</i>	WD, sdO, sdB	30	1,200-12,000	new

d) *Non-stellar sources*

In Section I we provided a list of catalogues of non-stellar objects. As with the stellar sources, the problem is to decide which catalogues are the most convenient and appropriate.

As a starting point, we endeavour to suggest:

ATLAS	NATURE	SOURCES	OBJECTS	##	WAVE-LENGTHS	STATUS
NGATLAS	Hybrid	Bruzual Pickles Fosbury	normal galaxies	5	1,200-12,000	new
					1,900- 9160	STECF
AGATLAS	Hybrid	?	active galaxies	a few	1,200-12,000	new
HPATLAS	Hybrid	Scheffler+?	HII (Orion)	1	1,200-12,000	new
	Hybrid	Kaler+?	PN	1	1,200-12,000	new
QSATLAS	Hybrid	Oke Turnshek	QSOs	3	1,200-12,000	new
?	?	Brown ? Paresce Computer	Solar System	a few	1,200-12,000	new
			Sky Bkgrd.	1	1,200-12,000	?
			Black Bodies	100	1,200-12,000	
			Power Law			

**Section III: A STANDARD GRID OF ENERGY
DISTRIBUTIONS FOR ASTRONOMICAL SOURCES**

Roland Buser

Astronomical Institute, University of Basel, Switzerland

and

Space Telescope Science Institute, Baltimore, Maryland, U.S.A.

ABSTRACT. We propose to construct a comprehensive STANDARD GRID of energy distributions for astronomical sources which matches the synthetic photometry software package developed at the STScI. The STANDARD GRID will be useful for the planning, evaluation, calibration, and interpretation of HST observations.

1. Introduction

The availability of a suitably constructed grid of spectral energy distributions for astronomical sources (henceforth referred to as the STANDARD GRID) is essential for the full exploitation of the instrumental capabilities of the Hubble Space Telescope (HST). Because the HST scientific instruments (SIs) have been designed on account of our current knowledge of the astronomical objects, the question has arisen naturally how this knowledge can be represented and made available in a compact and uniform manner, which enables us to (quantitatively) predict, evaluate, and compare the instrumental performances and the scientific capabilities of each SI by simulations of HST observations. Because each astronomical source will be observed in at most a few specific modes of the more than 120 photometric modes available with HST, it is natural again to ask for an efficient and sensible way of studying the *same* sources with *all* the observing modes, in order to develop a framework for the cross-correlation and the interpretation of the data. Finally, because HST observing time for instrumental *and* astrophysical calibrations will be very limited, it is necessary to face the question of how to take advantage of (pre-) existing knowledge and

calibrations of standard (e.g., ground based) spectrophotometric and photometric data in the calibration of the HST photometric system(s).

The STANDARD GRID is conceived to address these questions and provide most, if not all, of the astrophysical data necessary for their first-order solutions. In conjunction with the SI- and mode-specific response functions and a comprehensive software package, the STANDARD GRID makes up the integrated synthetic photometry tool described elsewhere. The use of this tool has been described, and the performance of a prototype has been demonstrated by Koornneef *et al.* (1986), who employed an small existing grid to predict the two-color diagrams and the transformations of normal Population I stars observed with the FOC-, WF/PC-, and HSP-analogs of the standard UBV system.

The present proposal covers the construction of a complete STANDARD GRID as part of the ongoing systematic photometry project that has been conducted, in collaboration with many people and institutions, at the Basel Observatory since 1972. The objective of this project naturally includes many tasks mentioned above, which have been identified as essential to the synthetic photometry approach of the calibration of the HST. The STANDARD GRID will allow users to perform realistic calculations relevant to the planning, evaluation, calibration, and interpretation of HST observations obtained through *all* photometric and spectrophotometric modes and of *all* known major types of astronomical objects. Although the STANDARD GRID is conceived as a temporarily frozen data library, it will be allowed to evolve and improve as new data will be coming in and as its intrinsic quality will be more fully evaluated through its use, e.g., with the next generation of simulators developed at STScI.

In what follows, I shall first give a brief review of the major difficulties that have opposed the completion of the STANDARD GRID in the past, and I shall briefly describe the prospects for its completion in the near future (section 2). Next, I shall describe the STANDARD GRID concept, emphasizing the intended improvement over the DEFAULT

GRID proposed in section II of this memo (section 3). Finally, I shall present a work and time schedule for a coordinated continuation of this project at Basel and at the STScI.

2. Historical Preamble

The main reason why the STANDARD GRID - whose concept will be developed below - has not yet come to exist, at least not in published or any other publicly accessible form, is that it has been difficult to establish. Because there has never been, to the best of my knowledge, an observational program directed towards an inventory of energy distributions representative of all known major types of astronomical objects in the universe, such an inventory must be compiled *a posteriori* from many different projects that have (had) their particular goals, instrumentations, reduction procedures, and even epochs. These constraints imply that the spectrophotometric data available for the compilation of the STANDARD GRID constitute a collection which is rather heterogeneous with respect to wavelength coverage, spectral resolution, calibration, and accuracy. Furthermore, with the exception of a few "workhorse" standard stars, the (often competitive) nature of the different projects hardly ever allows enough overlap of target sources to facilitate the construction of the STANDARD GRID. Finally, since the largest fraction of the spectrophotometric data are available for *field stars*, interstellar reddening presents an additional major difficulty to the derivation of a STANDARD GRID of accurate *intrinsic* stellar energy distributions.

Given these rather disadvantageous constraints, one may be inclined to doubt that construction of the STANDARD GRID is possible at all. However, I do not share these doubts, because I have been practising, with many colleagues and collaborators, synthetic photometry for more than a decade, and for good reasons. First of all, we have invested a sizeable fraction of the time collecting and using published energy distributions, and an even larger fraction discussing and searching, with many people, their unpublished yet valuable material. Although the systematic evaluation of these data is far from complete,

the aggregate appears to be of sufficient quality to provide STANDARD GRID input. Secondly, since the start of this program at Basel in the early seventies, there has been a favorable rise of interest in energy distributions among astronomers active in galaxy synthesis and population studies rather than individual stars and stellar atmospheres, and this has led to the recent publication of very useful data collections indeed (e.g., the Gunn-Stryker and the Jacoby et al. stellar spectrophotometric atlases, or the galaxy energy distributions by Pickles). Thirdly, satellite missions such as IUE remove, by their very nature, many of the above-mentioned difficulties and sources of inhomogeneities in the observed energy distributions, even though at the price of introducing other problems which must be taken care of instead. Indeed, it is very fortunate that IUE data for a large representative sample of stars has been made available in the form of atlases, which are really vital to our confidence in the feasibility of the STANDARD GRID. Finally, there has been a lot of significant progress in the area of theoretical stellar atmospheres. Optical and, with slightly less impressive successes, also near-infrared intermediate- and broad-band colors of an increasing number of stellar types are well matched by synthetic calculations from model atmospheres. This makes the models extremely useful in combining observed energy distributions for different objects and/or different wavelength ranges, as well as filling in gaps in, or providing realistic extrapolations of, the observed data. Even though the theoretical models are deficient in many - even curable - ways (see, e.g., Kurucz (1986) and Gustafsson (1986)), their differential properties are in general less deficient. They can thus be used efficiently to interpolate between observed stellar types and construct a STANDARD GRID that preserves the differential physical properties established from photometric observations.

In summary, while there *have* been serious problems, there has also been a great deal of real progress. Synthetic photometry is rapidly gaining momentum as an efficient and versatile tool in astronomy. This fact is reflected in the Stellar Photometry and Polarimetry IAU Commission's organizing the Joint Commission Meeting at the past IAU

General Assembly in India and supporting the creation of a Working Group on Synthetic Photometry (Tinbergen 1986, Buser 1986). It thus appears obvious that the HST and STScI, representing the most advanced facilities for the whole of astronomy, are most likely to profit most extensively from these developments in the future. This, in turn, also justifies the present proposal that STScI continue its activities as a major collaborator in this effort.

3. The STANDARD GRID concept

Like the DEFAULT GRID proposed in section II of this memo, the STANDARD GRID concept can be developed according to the following list of priorities, starting with the highest level of importance.

(1) Wavelengths and resolution

Each energy distribution in the STANDARD GRID should cover the whole wavelength range accessible to the scientific instruments (SI's) of HST. Fluxes should be given with a resolution matching that of the SI's, i.e., for a sufficient number of wavelength points to satisfy the purposes of synthetic photometry.

(2) Realism

Each energy distribution of the STANDARD GRID, and consequently, the STANDARD GRID as a whole, should provide synthetic colors (across the entire wavelength range) according to observed colors and standard relations to within the observational uncertainties (i.e., to better than approximately 0.02 mag in UBVRI).

(3) Sources

The STANDARD GRID should comprise intrinsic energy distributions for two broad categories of astronomical objects: stellar and non-stellar. Within each of these categories, there should be a representative energy distribution for each major object class. In the stellar case, this is equivalent to an essentially complete coverage of the observed HR diagram, i.e., the full ranges in effective temperatures, surface gravities, and metal abundances. In

the non-stellar case, this includes planetary nebulae, HII regions, normal galaxies, active galaxies, and QSO's.

(4) *Astrophysical nature*

Each energy distribution of the STANDARD GRID should be supplemented by a set of astrophysical parameter values (e.g., spectral type, luminosity class, effective temperature, etc.) which uniquely characterize the spectrum.

These requirements imply that the STANDARD GRID is being built up as a structured collection of hybrid energy distributions, each of which is constructed from a comprehensive pool of existing original and/or hybrid data on individual astronomical sources. In addition to the sources listed in Tables 1 through 4 of section I, the generation of the STANDARD GRID will also include as yet unpublished data from Table 5 below, which were recovered for this purpose during my stay at Caltech from the archival collections of multichannel observations of Oke and Greenstein.

While the main purpose of the DEFAULT GRID is to provide the most readily feasible extensions of the existing STScI libraries to full coverage of wavelengths (1) and sources (3), construction of the STANDARD GRID will go for significant improvements over the DEFAULT GRID in all the above-mentioned aspects (1) through (4), as follows.

(a) Population I

For population I objects, the extension of the IJ atlas spectra beyond 7,427 Å will include the PICS data to 10,000 Å, the GS data to 10,800 Å, and the K1200/KGBEN models to 12,000 Å rather than the KB data. Both the PICS and the GS data have been extensively tested for their photometric quality and found to be adequate. Since both the PICS and GS flux distributions are labeled with MK types, - as are those in the IJ atlas of the DEFAULT GRID -, the selection of matching spectra from the different atlases should pose little problems. This approach should improve on the resolution as well as the realism of the final population I STANDARD GRID.

(b) Population II

For population II objects, we shall use the data from the GCG, SUB, CHB, HB1, HB2, and CH optical atlases to first investigate the relation between globular cluster and field population II stars, in order to then deredden and join the optical and UV fluxes from the CH and UCH atlases, respectively. The use of cluster stars significantly reduces the level of uncertainty due to interstellar reddening, and thus also paves the way for examining how the intrinsic optical fluxes are matched by the K1200 and KBGBEN models, which will be used to connect the optical and UV data near the atmospheric cutoff. Furthermore, in the absence of a well-established system of spectral classes for population II stars, the cluster star data will, in conjunction with the model atmospheres, provide isochrones in the HR diagram and thus determine a well-defined grid of population II stars in terms of color, absolute magnitude, metallicity, and age. This approach should thus lead to improvements on the realism as well as the astrophysical nature aspects of the final population II STANDARD GRID.

(c) High-gravity stars

For the high-gravity stars, we will set up a grid of flux distributions defining two sequences in the log T_{eff} -log g diagram. The first is a pure temperature sequence for white dwarf stars at log $g = 8$ and with temperatures ranging from 100,000K down to 4,000K. We will use both observed data from the WDO and UWD, and theoretical data from the WES, TM, and SC atlases given in Tables 1 and 3. All these models have been shown to well match the optical observations. Missing UV observations for some of the cooler stars will be provided by extrapolation of differential colors calculated from the hotter stars and/or models. The second sequence will represent the advanced evolutionary phases preceding the white dwarf stage. These are blue horizontal branch (BHB) stars with temperatures between approximately 10,000K and 25,000K and with (log) gravities between about 3.5 and 5; sdB stars (20,000-30,000K; 5-6); sdOB stars (30,000-40,000K; 5-6.5); and sdO stars (>40,000K; 5-6(?)). We will use the observations from the HB1, HB2,

and CHB atlases in conjunction with the models from the K1200 and SH atlases. While the (cooling) white dwarf sequence will improve on the DEFAULT GRID because it will adequately represent an important stellar type with rather well understood astrophysical properties, the evolutionary sequence will provide a rough but indispensable abstract of our knowledge in a research field which is presently itself evolving at an extremely fast rate.

STANDARD GRID $\lambda_{1,200}-\lambda_{12,000}$

Atlas	Stars	Sequences	Parameters	No. of Spectra
PI	Pop. I	Main Subgiant/Giant Supergiant	O-M B-M O-M	} 70
PII	Pop. II	16 Gyr Isochrones	$[M/H] = \{-0.5, -1, -2\}$	
HG	High Gravity	WD Cooling Advanced Evol. Stages	$\left\{ \begin{array}{l} \log g = 8 \\ 10^5 K \geq T_{eff} \geq 4 \times 10^3 K \\ 7 \geq \log g \geq 3.5 \\ 5 \times 10^4 K \geq T_{eff} \geq 10^4 K \end{array} \right\}$	20

4. Work and time schedule

I suggest that the work described in the preceding section be done in collaboration at the Basel Observatory and at the Space Telescope Science Institute. Our own work in Basel will continue to concentrate on the population II and the high-gravity stars. I expect that this can be completed within nine months, with an upper limit of about one year from now.

If the STScI could start out with the work on population I, we would be able to meet again here for one or two weeks by the end of 1986, in order to discuss our achievements and coordinate the schedule for the remaining tasks. Completion and implementation of the STANDARD GRID would probably require another shorter visit at STScI around mid-1987.

TABLE 5

ATLASES OF STELLAR ENERGY DISTRIBUTIONS

Atlas Name	Source Reference	Types	Number	Wavelengths (\AA)	Resolution	Nature
HYA	Oke/Buser 1977	Hyades m.s. stars	13	3,340-11,360	40/80	OBS
M67	Oke/Buser 1977	M67 m.s. & sg stars	11	3,320-11,160	80/160	OBS
GCG	Oke/Buser 1977	G.C. giants	27	3,180-11,320	80/160	OBS
SUB	Greenstein/Buser 1977	high-vel sd F-M	82	3,100-11,000	40 320	OBS
HB1	Philip & Hayes 1983	Pop II field HB A stars	16	3,400-6,790	40 360	OBS
HB2	Hayes & Philip 1983	high-vel. field HB stars	9	3,410 6,840	160 360	OBS
CHB	Hayes & Philip 1983	G.C. HB A stars	11	3,410-6,840	160 360	OBS
PICS	Pickles 1985	Pop I O-M/III-V Pop II	200	3,600-10,000	10 17	HYB
B15	Straizys 1983	Pop I B-M/I-V	398	3,000-7,750	50	HYB
B25	Straizys 1983	Pop I B-M/I-V	176	3,000-11,000	50	HYB
BGL	Voloshina <i>et al.</i> 1982	Pop I O-M/I-V	735	3,225-7,625	50	OBS

TABLE 1. ATLASES OF OBSERVED STELLAR ENERGY DISTRIBUTIONS

Atlas Name Comments

GS This atlas contains a large number (175) of homogeneous SEDs for Population I stars. All the data were taken with the Oke (1969) multichannel spectrophotometer at the Cassegrain focus of the 5-m Hale telescope and reduced to the AB79 spectrophotometric system of Oke and Gunn (1983), which is based on the Hayes-Latham (1975) absolute calibration of Vega. Fluxes are given every 10Å blueward, and every 20Å redward of 5740Å, at resolutions of 20Å and 40Å, respectively. The apparent V magnitudes of the atlas stars range between 2.5 and 13, and about 30% of the stars are reddened by more than 0.03 mag in E(B-V). The atlas has been used successfully in synthetic calculations reproducing observed Johnson-UBV (Labhardt & Buser 1985; 117 stars), Cousins-VRI (Buser & Horne 1986; 21 stars), and Geneva photometry (Rufener 1986; 101 stars) to within less than 0.03 mag for all colors.

We recommend this atlas for its systemic homogeneity and proximity to the HST photometric system, its relatively high degree of broad-band photometric accuracy, and its extensive coverage in stellar types and wavelengths. Intrinsic flux distributions should be derived (e.g., Labhardt & Buser 1985) referring to the intrinsic colors as functions of MK class (e.g., FitzGerald 1970), rather than adopt them in the interstellar extinction model-dependent form published by Gunn and Stryker.

References:

- Buser, R. & Horne, K. 1986, in preparation.
 FitzGerald, M.P. 1970, *Astron. Astrophys.*, **4**, 234.
 Gunn, J.E. & Stryker, L.L. 1983, *Ap. J. Suppl.*, **52**, 121.
 Hayes, D.S. & Latham, D.W. 1975, *Ap. J.*, **197**, 593.
 Labhardt, L. & Buser, R. 1985, in: IAU Symp. No. 111, Calibration of Fundamental Stellar Quantities, D.S. Hayes, L.E. Pasinetti, A.G. Davis Philip (eds.), (Dordrecht: Reidel), p. 519.
 Oke, J.B. 1969, *Pub. A.S.P.*, **81**, 11.
 Oke, J.B. & Gunn, J.E. 1983, *Ap. J.*, **266**, 713.
 Rufener, F. 1986, in: IAU Joint Commission Meeting New Delhi, Synthetic Photometry, R. Buser (ed.), (STScI Preprint No. 100), p. 15.

JHC Again, this atlas contains a large number (161) of homogeneous SEDs for Population I stars (but none in common with the GS atlas), covering a wide range in spectral types (O to M) and luminosity classes (I, II, III, V). All the data were taken with the Intensified Reticon Scanner and the No 1. 0.9-m telescope at Kitt Peak National Observatory, and were reduced to the Hayes and Latham (1975) absolute flux system. Fluxes are given every 1.4 Å at a resolution of about 4.5 Å (which varies only slightly, < 10%, from the blue to the red limits of the spectra). The apparent V magnitudes of the atlas stars range from 8 to 11, and about 60% (100 stars) are reddened by more than 0.03 mag in E(B-V). All the spectra were dereddened by comparing their synthesized B-V with the intrinsic B-V for the same spectral and luminosity class from FitzGerald (1970); for 22 stars, this procedure requires spectral types different from the published types by up to a few subclasses (in two cases, even the luminosity class had to be adopted different). Furthermore, most of the adopted spectral types for the 19 O-stars included in the atlas would need to be revised in order to conform to the current MK system (Walborn 1985). This again illustrates one of the major difficulties in creating homogeneous spectrophotometric libraries with known intrinsic *astrophysical* properties.

Despite its relatively limited wavelength coverage we recommend this atlas for its higher resolution than most other atlases. The photometric quality must however be checked, in addition to Johnson B-V, against intermediate-band observations, which, unfortunately, are still not available for most of the atlas stars.

References:

Jacoby, G.H., Hunter, D.A., Christian, C.A. 1984, *Ap. J. Suppl.*, **56**, 257.
Walborn, N.R. 1985, priv. comm. to J. Koornneef.

UNA/UES These two atlases contain UV data obtained from IUE measurements of normal (Population I) stars covering a wide range in spectral types and luminosity classes. Even though they have only 10 (early type) and (2JHC O main sequence) stars in common with the GS and JHC atlases, respectively, they represent the most readily available complementary sources to the optical data suggested for the construction of the Population I grid.

In fact, they have already been used along with the JHC atlas in setting up the STScI-FOS spectra library (Ford 1986, Ciardullo and Testa 1986); while this presently existing library of hybrid flux distributions is probably adequate for exposure time calculations, extensive testing of its photometric quality will be necessary in order to evaluate its suitability for the more ambitious uses intended with the HST calibration effort. Furthermore, the UNA/UES spectra in common with the GS

atlas have been used successfully by Labhardt and Buser (1985) in extending the GS spectra to the atmospheric cutoff at 3000 Å and evaluating their consistency with observed UVB data.

References:

Ciardullo, R., Testa, C. 1986, private communication.

Ford, H.C. 1986, private communication.

Heck, A., Egret, D., Jaschek, M., Jaschek, C. 1984, IUE Low-Dispersion Spectra Reference Atlas - Part I. Normal Stars. ESA SP-1052, Paris.

Wu, C.C. *et al.* 1983, The IUE Ultraviolet Spectral Atlas, NASA Newsletter No 22 (Special Ed.).

CH/UCH These two atlases will provide major inputs into the Population II grid. They contain 36 field-population II stars (subdwarfs, subgiants, giants, and horizontal branch stars) in common, with the CH data for the optical and near-IR, and the UCH data for the UV. 28 of these common stars have $[Fe/H]$ values determined from high-resolution spectroscopy and/or optical photometry - their generally low metallicities being one of the Population II signatures -, and have been studied intensively by various groups.

Although not at all a homogeneous stellar sample in any physical sense, the large amount of (partly controversial) astrophysical information now available for these stars makes them primary candidates for grid input.

The CH data were taken with the Mt. Wilson Cassegrain scanner (Oke 1964) using both the 1.5- and 2.5m telescopes, and reduced to the Oke and Schild (1970) absolute calibration of Vega. Fluxes are given for between 35 and 44 wavelength points, selected primarily for their relevance to galaxy synthesis, and sampling 20 Å bandwidths shortward of 4800 Å and 30 Å bandwidths in the red.

The apparent V magnitudes range between 4 and 9.5, and about 10 stars have $E(B-V) > 0.03$. For 3 stars whose color excesses were known at the time, the flux distributions were dereddened; for the rest, the published results are presented as observed.

The UCH data were taken with IUE by Cacciari (1985); fluxes are given at 5 Å intervals between 1155 Å and 3195 Å or 1955 Å and 3195 Å for the cooler stars. These data were obtained with the purpose of providing a grid of metal-poor stars necessary for population studies of stellar systems.

References:

Cacciari, C. 1985, *Astron. Astrophys. Suppl.*, **61**, 407.

Christensen, C.G. 1978, *A. J.*, **83**, 244.

Oke, J.B. 1964, *Ap. J.*, **140**, 689.

Oke, J.B. and Schild, R.E. 1970, *Ap. J.*, **161**, 1015.

WDO/UWD These two atlases cover the optical (WDO) and the UV (UWD) flux distributions for white dwarf DA and DB stars. The two atlases have six stars in common, five and four of which are HST UV- or OCTWG blue stars standards, respectively. Thus, these stars are among the very few *HST calibration targets*, for which continuous energy distributions can be made available at the present time. These energy distributions should be constructed (even though new observations - both optical and UV - of these same stars are currently being obtained by Oke (cf. Koornneef *et al.* 1984)), because they will serve as primary test data for the pre-launch calibration effort described by Koornneef *et al.* (1986) before the updated fluxes will be available. Furthermore, these few flux distributions will suffice as the reference points necessary to build up a consistent and extended grid of high-gravity stellar spectra from the model atmospheres to be described below.

The WDO stars were observed with the Oke (1969) multichannel spectrometer at the Hale 5m telescope and reduced to the AB69 system, which is based on the Oke and Schild (1970) absolute calibration of Vega. Fluxes were measured with bandpasses of 20-80 Å in the blue (< 5700 Å) and of 40-360 Å in the red, depending on the apparent brightness of the star, and are given at wavelengths separated by the widths of the bandpasses. The apparent V magnitudes range between 9.5 and 15.5; because these are all nearby stars, interstellar reddening is negligible.

The UWD data were obtained from IUE observations and have been made available to the FOS and the FWSIM stellar libraries by Bohlin (Ewald 1986).

References:

Ewald, S.P. 1986, private communication.

Koornneef, J., Baum, W.A., Bohlin, R.C., Dolan, J., Oke, J.B., Turnshek, D.A. 1984, 'Report of the Optical Calibration Target Working Group'.

Oke, J.B. 1974, *Ap. J. Suppl.*, **27**, 21.

TABLE 2 ATLASES OF THEORETICAL STELLAR ENERGY DISTRIBUTIONS

Atlas Name Comments

K1200 This atlas contains a very large number of model atmospheres calculated for stars hotter than 5500K by Kurucz (1979b). The models are fully blanketed LTE and cover gravities appropriate for supergiants up to main-sequence and subdwarf stars, and metallicities between ten times solar (extreme Pop.I) down to zero (Pop.III).

The grid is composed of essentially three types of models, as follows.

Number	T_{eff}	log g	[M/H]	Description/Ref.
1-284	5500-50000	0.00-5.00	0.00-(-2.00)	Kurucz (1979a), Buser & Kurucz (1978).
285-609	8000-20000	1.00-4.50	1.00-(-1.00)	purely radiative; Kurucz (1979b), Buser & Kurucz (1986).
610-1200	5500-8500	0.00-4.50	1.00-(-9.99)	improved convective; Kurucz (1979b), Buser & Kurucz (1985, 1986)

The first 284 models are the well-known models that have been fully published and have enjoyed widespread use. Models 285 through 609 are purely radiative models having parameters appropriate for the more detailed study of A and B stars, including peculiar stars such as Am. The last block of 591 models include a slightly modified treatment of convection, as prompted by the various failures of the earlier models in matching observations for F and G stars. Also, the metallicity parameter has been allowed to cover the full range of expected values. While the coolest of these models still do not reproduce the observed colors of solar-abundance stars to within the desired accuracy, they do predict the (optical and near-IR) color variations as functions of T_{eff} and [M/H] in excellent agreement with observations (Buser & Kurucz 1985, 1986). They are thus most valuable for differential studies and, in particular, for the purposes of combining observed flux distributions to construct an astrophysically consistent grid. Most importantly, these models will be major inputs to the Population II grid, where UV observations are scarce.

References:

- Buser, R. and Kurucz, R.L. 1978, *Astron. Astrophys.*, **70**, 555.
- Buser, R. and Kurucz, R.L. 1985, in IAU Symp. No. 111: Calibration of Fundamental Stellar Quantities, D.S. Hayes, L.E. Pasinetti, A.G. Davis Philip (eds.), (Dordrecht: Reidel), p.513.
- Buser, R. and Kurucz, R.L. 1986, in preparation.
- Kurucz, R.L. 1979a, *Ap. J. Suppl.*, **40**, 1.
- Kurucz, R.L. 1979b, in Problems of Calibration of Multicolor Photometric Systems, A.G. Davis Philip (ed.), Dudley Obs. Rep. No. 14, p. 363.

KBBEN This atlas provides as yet unpublished theoretical model atmosphere flux distributions for late-type (F-K) stars computed by Buser and Kurucz (1986) as part of the systematic long-term project (A Systematic Investigation of Multicolor Photometric Systems) conducted at the Basel Observatory, where we have been working toward the construction of a comprehensive grid of stellar energy distributions (covering essentially the whole HRD) suitable for the calibration, transformation, and interpretation of survey data obtained on many different photometric systems. The models in this atlas represent our currently adopted best extension of the theoretical grid (which includes the massive Kurucz (K1200) grid as well as the high-gravity grids to be discussed below) to the cooler stars, including late-K types at 4000K.

In order to satisfy our needs to treat photometric data covering essentially the entire optical and near-IR wavelengths, which in particular includes the metallicity-sensitive near-UV, we decided to generate new fluxes from the grid of late-type giant model atmospheres published by Gustafsson et al. (1975), as well as from these same authors' unpublished grid for late-type dwarf stars. It has long been known that the fluxes produced from these models by Gustafsson *et al.* themselves (e.g., Gustafsson & Bell 1979 for the giants) are extremely poor, if not useless, at wavelengths shortward of about 4500 Å, where line blanketing due to atomic opacity sources starts to have significant effects on the energy distributions (see, e.g., also Gustafsson 1986). Rather than concentrating - as was the objective of Gustafsson *et al.* - on the molecular opacities, which become important at near-IR wavelengths, we have generated fluxes using the massive list of atomic absorbers compiled by Kurucz and Peytremann (1975). Our subsequent synthetic UVB photometry results indeed improve the UV colors dramatically (Buser & Kurucz 1985); but rather less expectedly, they also seem to provide improved VRI colors; it appears likely now that backwarming from the UV blanketing outweighs or at least compensates favorably the neglected effects of the molecules on these colors (Buser & Kurucz 1986).