Spectral Atlas File Contents

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Abstract

We define the information that can be contained in a solar spectral atlas file, how that information can be organized in a FITS file, and the metadata contents and formatting used to describe the spectral atlas contents.

Introduction

Solar spectral atlases are intended to be reference datasets providing the intensities of the solar spectrum uniformly covering an extended wavelength interval. They are generally derived from one or more observations taken under specific conditions. In order to provide a stable reference, not affected by spatial or temporal inhomogeneities, they are often averaged in space or time. As such, the atlases are provided as only a single dimension array, in wavelength. The key aspect of many atlases is to capture the position, strength, and shape of multiple spectral lines (absorption or emission) present in the solar spectrum. This is most widely used to provide a comparison to separate, individual observations of the solar spectrum using a broad range of instruments.

In order to properly characterize the solar intensities, the observations are precisely calibrated to remove as many instrumental effects as possible. This can include absolute wavelength calibration, stray light removal, and relative intensity fluctuations. Since a basic goal of many atlases is to cover as large of a spectral range as possible, they are often obtained in multiple segments (due to limits on detector size or sampling resolution) which are later combined into a contiguous series. Smearing due to the finite spectral resolution of any real instrument however is typically not removed from the atlas, but rather the known spectral resolution of the instrument is provided, either by characterizing the FWHM of the spectral transmission profile or providing its actual measured profile (which may be asymmetric). This spectral resolution calibration may also have a wavelength dependence.

Another significant issue in spectral atlases obtained from the ground is the presence of overlaid absorptions from the Earth's atmosphere. These can obviously confound the interpretation of the solar spectrum (while for others they may be the topic of study!). Observation techniques have been used in the past to separate these two components, by identifying which lines change their strength as they are observed through different airmasses. Newer tools allow a more robust calculation of the terrestrial (or *telluric*) spectrum using full radiative transfer calculations of multiple species. These calculations can be used to calibrate existing atlases, or produce theoretical spectra that can be used to calibrate specific measurements.

Beyond the presence of distinct spectral lines, the solar spectrum shows significant trends in intensity with wavelength, most strongly because of the underlying black-body profile of the region of the atmosphere being measured. Since this can confound the comparison with specific observations, which generally cover a limited spectral range and are normalized to the local intensity, solar spectral atlases often remove the large scale trends in continuum intensity. This provides a uniform continuum intensity around unity (or some reference value) for the entire atlas. Such atlases are no longer able to provide a true flux calibration, though local flux calibration can typically be reapplied if needed.

We define here the potential contents of a data file that contains a "solar spectral atlas." Such a file may contain multiple components that include solar, terrestrial, or instrumental information used to visualize, interpret, and apply the solar spectrum. This information may be stored as metadata elements or data arrays.

Atlas Components

- Solar Spectral Integrated Flux Atlas [F_λ] – A flux atlas provides the spectral intensity of the Sun as a function of wavelength *integrated over the entire disk.* This is useful for characterizing the total solar output or for comparison with other sun-as-a-star or stellar measurements. However, observing at different viewing angles (perpendicular at the disk center to tangential at the limb) generally means different path lengths and sensitivity to different heights in the solar atmosphere across the disk. This means that the shape of the continuum and relative strength of different spectral lines is spatially varying across the disk. The integrated flux atlas mixes these contributions and is less useful for comparison to a measurement of a specific location on the Sun.

- Solar Spectral Intensity Atlas [I_λ] – The spectral intensity atlas instead provides a reference spectrum taken over a limited area on the solar disk. This means it provides a more direct and specific measurement to compare with observations or models. Typically these spectra have been taken in a region of "quiet" Sun near disk center, but there are some taken at a different distance from Sun center or covering specific solar features. The use of the term *intensity* implies that the local continuum at each wavelength has been normalized to a reference value to remove large-scale trends in absolute flux (typically such that local continuum = 1).

- Solar Spectral Flux Atlas [I^f_λ] – This is similar to the intensity atlas, but the retains information on the black-body profile or other underlying intensity trends in the spectrum, as well as information on spectral line absorbtions at any given wavelength.

- Solar Continuum Flux Atlas [C^f_λ] – This is similar to the spectral flux atlas, but the estimated continuum flux only, as a function of wavelength. Spectral features are removed to the extent possible. The trends in the continuum level can be combined with a spectral intensity atlas, to determine an absolute intensity at each wavelength (creating a spectral flux atlas).

- Telluric Spectrum – A telluric spectrum provides the absorption caused by observations through the Earth's atmosphere. Unlike the somewhat steady solar spectrum, this absorption can vary significantly in time due to changes in the atmospheric conditions (humidity, pressure, temperature) and also changing path lengths as the Sun's altitude varies during the day from a given observing location. Therefore, the telluric spectrum seeks to provide a measurement of the strength of the terrestrial absorption lines in specific conditions. Some spectral atlas products provide these as a byproduct of the calibration process (namely the Fourier-Transform Spectrometer atlases from Kitt Peak). Since for a range of airmasses the telluric absorption scales mostly linearly, the telluric spectrum can be provided as a relative strength (*i.e.* absorption per airmass). For theoretical calculations, the absorption can be calculated for a specific viewing geometry.

- Spectral Resolution – The spectral resolution provides an indicator of the finite smearing cause by the instrument used to produce the atlas. This is important because such smearing can change the shape of the observed spectral profiles. Even for the instruments that minimize this effect, the shape of the spectral profiles can be noticeably altered. Atlases might provide measurements of the spectral resolution at different wavelengths to capture its variation. This is most often reported as a FWHM or a spectral resolution $R = \frac{\lambda}{FWHM}$. In other cases the actual spectral transmission profile might have been measured at discreet wavelengths (*e.g.* using a laser).

Atlas File Format

Different atlases will have provide different sets of the components described above. An atlas may typically provide a spectral flux or local intensity component. Some atlases, like the Kitt Peak atlases generated by the National Solar Observatory, provide separate solar and telluric components, while others do not provide such a differentiation. Some "atlases" may provide only the telluric component such that it can be used to correct other spectral measurements. In addition, a given atlas may include discontinuities in spectral coverage. This may be the case for infrared atlases, where strong absorption bands in the telluric spectrum preclude meaningful observations observations over large intervals. Because some instruments that only sample a few specific lines, it may be advantageous to provide a file containing only the atlas spectral lines in only those windows of instrumental operation. Therefore, the spectral atlas file format should be flexible about which components may be contained in a given file and the inclusion of multiple spectral segments.

In order to provide sufficient flexibility, and the ability to fully describe the individual components, the spectral atlas files will be in FITS format and using the binary table convention to store the wavelength scale and intensity or flux components. Each binary table will include one column with the wavelength value at each sampling position. Each additional column will be a different atlas component with samples at each of the wavelength positions. The header for the binary table extension will contain information on each particular component (i.e. table column) and and characterize its contents (in terms of range, units, source, etc.). Multiple binary tables can be stored in separate extensions to incorporate separate, spectrally disjoint segments of the atlas [1]. The primary header unit will also contain general

[1]While disjoint spectral segments could also be stored in a single binary table, relying

information applying to all the components and segments of the atlas. The different components may be stored in any order in the binary table, which can then be extracted based on the column definition keywords.

Header Definition

The following keywords can be used to define the contents of a spectral atlas file. Some metadata elements may in some cases apply globally to the entire atlas, or may be specific to a given component. In the latter case, the metadata element will be defined following the binary table column keyword convention. For accommodate different ways of defining these parameters, we define two versions of the keywords that might be used to specify the metadata element. If the metadata information is specified at the column level for one component, it should be specified separately for all columns where it is applicable and the corresponding *global* keyword should **not** appear in the primary or extension header.

on a non-continuous wavelength scale definition, it will likely be easier to process and display the atlas components if the distinct segments are stored separately.

Keyword	Definition	
	Units	**Allowed Values**
OBJECT	the primary target for the observations in the data array	
TOBJCn	N/A	[Sun,Earth Atmosphere]
BUNIT	the units for the values stored in the data array	
TUNITn	N/A	['RELINT', 'FLUX']
CTYPEn	the physical axes being measured	
	N/A	['WAVE', 'AWAV']
CRVALn	the value along axis n at pixel position CRPIXn	
	[nm,Å,μ,mm]	[0-1e6]
CRPIXn	the pixel position at which the reference value in CRVALn applies	
	[pixel]	N/A
CDELTn	the change in value per pixel along axis n at pixel position CRPIXn	
	[nm,Å,μ,mm]	[0-1000]
CUNITn	the units for the CRVALn and CDELTn keywords	
	N/A	['nm','Angstrom','micron','mm']
WAVEREF	specifies whether air or vacuum wavelengths are used	
	N/A	['vacuum', 'air']
WAVEMIN	the minimum wavelength covered by atlas	
	[nm,Å,μ,mm]	[1-100000]
WAVEMAX	the maximum wavelength covered by atlas	
	[nm,Å,μ,mm]	[1-100000]
WAVEUNIT	power of 10 of the meter for wavelength units	
	N/A	[-10, -9, -6, -3, 1]

Keyword	Units	Definition Allowed Values
ATL_TYPE		the type of atlas component stored in the file
TTYPEn	N/A	['Integrated Flux', 'Integrated Intensity', 'Local Intensity', 'Local Flux', 'Flux Profile', 'Telluric Spectrum', 'Wavelength Scale', 'Data Validity', 'Instrumental Profile']

Note: when using the TTYPEn keywords in a binary table header, it is strongly recommended, as per the FITS specification, to enforce uniqueness for all TTYPE values of a given binary table. Therefore, each of the above allowed values shall be followed by a variable number of spaces and a unique index number for each instance of a repeated atlas component type in that table. The same value for TTYPEn can be used in different binary tables stored in the same FITS file. The index value has no significance except enforcing uniqueness.
For example, 'Local Intensity 1' and 'Local Intensity 2'

Keyword	Units	Definition Allowed Values
ATLMETHD	the method by which the atlas component was produced	
TMTHDn	N/A	['Observation - Direct', 'Observation - Derived', 'Calculated - Theoretical', 'Calculated - Radiative Transfer', 'Not Applicable']
ATL_DATE	an indicative date for when the atlas data were acquired	
	ISO-8601	yyyy-mm-dd[THH:MM:SS)
ATLTARGT	descriptive name of solar feature sampled by atlas	
TTRGTn	N/A	['Quiet Sun', 'Sunspot', 'Full Disk', 'Limb', 'None]

Keyword	Units	Definition Allowed Values
ATLSOURC	N/A	the source from which the atlas was obtained
ATL_NAME TDESCn	N/A	the common name by which the atlas if referred
ATL_TITL TTITLn	N/A	the title to be used on atlas plots
ATL_LABL TLABLn	N/A	the short label to be used on atlas plots
ATL_REFn	N/A	a citation for a publication describing atlas Author, Year, Journal, Volume
ATL_ADSn	N/A	an ADS URL for a publication describing atlas
ATL_YEAR	N/A	indicative year for release/announcement of atlas

Keyword	Definition Units	 Allowed Values
ATL_MU	the $\mu = \cos\theta$ value of the atlas integration area[2]	
TMUn	[unitless]	[0-1]
ATL_RAD	the average distance from Sun center of the atlas integration area	
TRADn	[$R_\odot$] (solar radii)	[0-2]
ATL_AREA	the spatial area over which the atlas was integrated	
	[arcsec^2]	[1 - 3×10^6]
ATL_AIRM	the approximate airmass during atlas measurement	
TAIRMn	$1/\cos(\theta_{zenith})$	[0-10] (where values below 1 indicate no atmospheric component)
ATL_WATM	whether or not the atlas includes a telluric component	
TWATMn	N/A	['T','F']
ATL_MISS	data value for missing or undefined data points	
TMISSn	N/A	[0, -1]
ATL_SAMP	denotes whether wavelength sampling of atlas is evenly spaced in wavelength units	
TSAMPn	N/A	['uniform','non-uniform']
ATLRSLTN	an indicative value for the spectral resolution of the atlas	
	[unitless]	[1-1000000]
ATLRESMN	an indicative *minimum* value for the spectral resolution of the atlas	
	[unitless]	[1-1000000]
ATLRESMX	an indicative *maximum* value for the spectral resolution of the atlas	
	[unitless]	[1-1000000]

Keyword	**Definition**	
	Units	**Allowed Values**
ATM_TEMP	the local temperature when atlas spectrum was acquired	
TTEMP*n*	C	[-100 – 50]
ATMPRESS	the local atmospheric pressure when atlas spectrum was acquired	
TPRES*n*	Pa	[0 – 110000]
ATM_PWV	the local precipitable water vapor when atlas spectrum was acquired	
TPWV*n*	mm	[0 – 100]
ATMHUMID	the local humidity when atlas spectrum was acquired	
THUMD*n*	%	[0 – 100]
ATL_LAT	the latitude of the location where the atlas spectrum was acquired	
	deg	[-90 – 90]
ATL_LONG	the longitude of the location where the atlas spectrum was acquired	
	deg	[-180 – 180]
ATL_ALT	the altitude of the location where the atlas spectrum was acquired	
	m	[0 – 6000]
ATL_OBS	Name of site or observatory where atlas was acquired	
	N/A	