

Plotting SEDs in the AVO prototype:
 Catalog Requirements, Conventions and Conversions

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1. Introduction

This document summarises the current status of plotting SEDs from Aladin in the AVO SED tool, including the magnitude to flux density conversions that are currently supported, and the VOTable requirements necessary for this to work.

The motivation for writing these notes is to provide a definitive set of information about photometry in the AVO prototype, and to help "close the loop" for plotting re-extracted catalog i.e. to specify the changes required to be able to plot ACE results in the SED tool. For the demo, this simply boils down to having the correct UCDS and column names in the VOTable.

For the future, we will need to give serious thought to a more general purpose modular "unit conversion" or "mag to flux conversion" tool or web-service.

2. VOTable sent to SED from Aladin

When the SED button in Aladin is pressed, Aladin sends SED a VOTable with the following fields:

name	UCD	unit
-----	-----	-----
_OID	ID_NUMBER	
frequency	OBS_FREQUENCY	Hz
delta frequency	INST_FILTER_FWHM	Hz
flux	PHOT_FLUX_DENSITY	Jy
error on flux	ERROR	Jy

(_OID is for callback purposes)

3. Catalog requirements for SED compatibility

The difficulty is to generate such a table from the many different sorts of catalogs with photometric measurements in different bands, units etc etc. We don't attempt to solve this problem in general, but rather support a limited number of modes.

- Catalogs in magnitudes: Generic
 - EIS single band catalogs
 - EIS cross matched catalogs
- Catalogs in physical units (Jy, Hz)

These different modes are identified by sets of UCDS and column names. The ones relevant for ACE output are Generic, and Catalogs in physical units.

3.1. Catalogs in magnitudes

3.1.1 Generic magnitudes

A VOTable with the following specific UCDS will be identified as a table with generic magnitudes in UBVR-IJHK bands. The VOTable must however also have names that link the magnitude and its corresponding error (the ERROR UCD problem) by using the e_ convention. The list below shows examples of U and e_U etc. The names can be whatever you like, but must uphold the e_ convention.

name(eg)	UCD (specific)
U	PHOT_MAG_U
e_U	ERROR
B	PHOT_MAG_B
e_B	ERROR
V	PHOT_MAG_V
e_V	ERROR
R	PHOT_MAG_R
e_R	ERROR
I	PHOT_MAG_I
e_I	ERROR
J	PHOT_MAG_J
e_J	ERROR
H	PHOT_MAG_H
e_H	ERROR
K	PHOT_MAG_K
e_K	ERROR

Currently ACE does provide the capability of tagging the result with the PHOT_ UCDS listed above. To make the result plottable in the SED tool, we require that the ERROR UCD is also included, and that the e_ convention on the field names be applied.

Below is a portion of a modified VOTable result from ACE where the following changes have been made to make it SED compatible:

- i) field name MAGERR_AUTO changed to e_MAG_AUTO
- ii) UCD="ERROR" added

This VOTable has been tested in the latest development versions of Aladin being prepared for the Sydney IAU demo. (v0.919 from the January 2003 demo had a little bug that prevents this from working)

```

<?xml version="1.0" encoding="UTF-8"?>
<VOTABLE version="1.0">
  <DESCRIPTION>SExtractor results</DESCRIPTION>
  <DEFINITIONS>
    <COOSYS ID="myJ2000" equinox="2000" epoch="2000" system="eq_FK5"></COOSYS>
  </DEFINITIONS>
  <RESOURCE name="GSC1.2">
    <DESCRIPTION>SExtractor configuration (input)</DESCRIPTION>
    <TABLE>
      <DESCRIPTION>SExtractor result catalogue</DESCRIPTION>
      <FIELD ID="ID" datatype="int" name="ID" ucd="ID_MAIN" />
      <FIELD ID="FLUX_ISO" datatype="float" name="FLUX_ISO" />
      <FIELD ID="MAG_ISO" datatype="float" name="MAG_ISO" />
      <FIELD ID="RA" unit="deg" datatype="float" name="RA" ucd="POS_EQ_RA_MAIN" />
      <FIELD ID="DEC" unit="deg" datatype="float" name="DEC" ucd="POS_EQ_DEC_MAIN" />
      <FIELD ID="MAG_AUTO" datatype="float" name="MAG_AUTO" ucd="PHOT_MAG_V" />
      <FIELD ID="MAGERR_AUTO" datatype="float" name="e_MAG_AUTO" ucd="ERROR" />
      <FIELD ID="FLUX_BEST" datatype="float" name="FLUX_BEST" />
      <FIELD ID="FLUXERR_BEST" datatype="float" name="FLUXERR_BEST" />
      <FIELD ID="MAG_BEST" datatype="float" name="MAG_BEST" />
      <FIELD ID="MAGERR_BEST" datatype="float" name="MAGERR_BEST" />
      <FIELD ID="CLASS_STAR" datatype="float" name="CLASS_STAR" />
      <FIELD ID="ELONGATION" datatype="float" name="ELONGATION" />
      <FIELD ID="ELLIPTICITY" datatype="float" name="ELLIPTICITY" />
      <DATA>
        <TABLEDATA>
          <TR>
            <TD>1</TD>
            <TD>915.635</TD>
          </TR>
          ...
        </TABLEDATA>
      </DATA>
    </TABLE>
  </RESOURCE>
</VOTABLE>

```

3.1.2 EIS single band catalogs

EIS single band catalogs are identified by the UCDS and column names of the EIS J/A+A/379/740/ catalogs in Vizier.

name	UCD
Mtot	PHOT_INT_MAG_U
e_Mtot	ERROR
Mtot	PHOT_INT_MAG_B
e_Mtot	ERROR
Mtot	PHOT_INT_MAG_V
e_Mtot	ERROR
Mtot	PHOT_INT_MAG_R
e_Mtot	ERROR
Mtot	PHOT_INT_MAG_I
e_Mtot	ERROR

(Note that there are no error-value association problems here because each band is in a separate catalog)

3.1.3 EIS cross matched catalogs

The draft EIS-CC catalogs are identified by the UCDs and column names of the EIS-CC II/234/ catalogs in Vizier.

name	UCD
Umag	PHOT_JHN_U
e_Umag	ERROR
Bmag	PHOT_JHN_B
e_Bmag	ERROR
Vmag	PHOT_JHN_V
e_Vmag	ERROR
Rmag	PHOT_COUS_R
e_Rmag	ERROR
Imag	PHOT_COUS_I
e_Imag	ERROR
Jmag	PHOT_JHN_J
e_Jmag	ERROR
Kmag	PHOT_JHN_K

(Note that error-value associations are done via the e_ convention on the column names)

3.2. Catalogs in Physical Units

In addition to magnitudes we also support fluxes already in physical units, that is, frequencies and bandwidths in Hz, and flux densities and errors in Jy.

The requirement for these sorts of tables to be plottable in the SED tool is that they contain the full set of UCDs listed below, AND also follow the e_ convention for the flux and error names.

UCD	name
POS_EQ_RA_MAIN	
POS_EQ_DEC_MAIN	
PHOT_FLUX_DENSITY	banana
ERROR	e_banana
OBS_FREQUENCY	
INST_FILTER_FWHM	

3.2.1 ACE

There has been some motivation to have ACE SExtractor also work in "physical units mode". Under the current system, ACE results in physical units could be displayed by having the catalog tagged with the above UCD and with the e_ field name convention.

4. Magnitude to flux conversion procedure

4.1 Vega flux standards used

The basic conversion of (Vega) magnitudes to fluxes is done using the V=0 flux table for Johnson-Cousins-Glass UBVR_IJHKLM system published in

Bessell, M.S. "Magnitude Scales and Photometric Systems" Reference Encyclopedia of Astronomy and Astrophysics 1991.

	U	B	V	R	I	J	H	K	L	M
lambda_eff (nm)	367	436	545	638	797	1220	1630	2190	3450	4750
delta lambda (nm)	66	94	85	160	149	213	307	390	472	460
F_nu(V=0)(10^-30Wcm^-2Hz-1)	1790	4063	3636	3064	2416	1589	1020	640	285	154

nb. (10^-30Wcm^-2Hz-1) == Jy

The following table was derived from this info to provide zero points for conversion of magnitudes to flux density in Jy.

FILTER	FREQ_EFF_Hz	DELTA_FREQ_Hz	ZP
U	8.4735008e+14	6.7059927e+13	8.1321326
B	6.5801681e+14	6.5353952e+13	9.0221171
V	5.6119891e+14	4.7274337e+13	8.9015597
R	4.6827938e+14	5.8333771e+13	8.7157219
I	3.5125068e+14	2.8540404e+13	8.4577423
J	2.4573152e+14	2.1451153e+13	8.0028097
H	1.8392175e+14	1.7320239e+13	7.5215004
K	1.3689153e+14	1.2188972e+13	7.0154499

4.2 Formulae for conversions

The formulae for the flux and uncertainty are:

$$\text{Flux} = 10^{(0.4(\text{ZP} - \text{mag}))}$$

$$\text{sigma_Flux} = \text{Flux} \cdot (\text{sigma_ZP}^2 + \text{sigma_mag}^2)^{(0.5)} / 2.5 \log(e)$$

(note we use sigma_ZP = 0)

4.3 UCD <-> ZP mapping

Once a catalog is identified from the UCDs and column names the magnitude values are converted to fluxes using the appropriate zero point.

The mappings of the UCDs to the ZPs (from the above table) are as follows:

FILTER	UCDs	ZP
U	PHOT_MAG_U, PHOT_INT_MAG_U, PHOT_JHN_U	8.1321326
B	PHOT_MAG_B, PHOT_INT_MAG_B, PHOT_JHN_B	9.0221171
V	PHOT_MAG_V, PHOT_INT_MAG_V, PHOT_JHN_V	8.9015597
R	PHOT_MAG_R, PHOT_INT_MAG_R, PHOT_COUS_R	8.7157219
I	PHOT_MAG_I, PHOT_INT_MAG_I, PHOT_COUS_I	8.4577423
J	PHOT_MAG_J, PHOT_JHN_J	8.0028097
H	PHOT_MAG_H,	7.5215004
K	PHOT_MAG_K, PHOT_JHN_K	7.0154499

4.4 Special Case (AB-Vega)

The EIS single passband catalogs are in AB magnitudes rather than Vega magnitudes, so a correction is applied prior to the conversion to flux.

The AB - Vega conversions are listed in Arnouts et al. 2001.

$$\begin{aligned} U'_{eis}(AB) &= U'_{eis} + 1.04 \\ U_{eis}(AB) &= U_{eis} + 0.80 \\ B_{eis}(AB) &= B_{eis} - 0.11 \\ V_{eis}(AB) &= V_{eis} \\ R_{eis}(AB) &= R_{eis} + 0.19 \\ I_{eis}(AB) &= I_{eis} + 0.50 \end{aligned}$$

so the following conversion is applied:

$$\begin{aligned} U_{mag} &= U_{mag} - 0.80 \\ B_{mag} &= B_{mag} + 0.11 \\ V_{mag} &= V_{mag} \\ R_{mag} &= R_{mag} - 0.19 \\ I_{mag} &= I_{mag} - 0.50 \end{aligned}$$

5. Scientific caveats

5.1 Cross Match

At present there is no cross-match capability in the AVO prototype. This means that there is no way to associate points in different catalogs so that they are presented as a single SED with all the points connected by lines. Only catalogs in cross-matched form, such as the EIS-CC catalogs, where each row of the catalog has multiple photometric points, can be drawn as connected dots in the SED tool.

Points from different catalogs can however be overlaid, and plotted together by selection in the Aladin window. The points will however not be joined by lines. This can cause confusion when plotting the SEDs of many sources at the same time.

5.2 EIS Catalogs:

5.2.1 U'

A specific UCD and ZP are not included U' because it is not clear which ZP to use.

5.2.2 EIS Colour Terms

The colour terms for the EIS catalog are NOT implemented in the AVO prototype system.

The EIS catalogs are calibrated to the Johnson system (as stated in Arnouts et al 2001), but the values in the EIS cross matched colour catalogs are EIS system vega magnitudes. i.e. to convert to Johnson one needs to apply the colour terms:

The most recent colour terms were provided by S. Arnouts. (to correct errors in the Arnouts et al 2001 paper)

$$(U_{jc} - U'_{eis}) = 0.04 (U' - B)_{eis}$$

```
(Ujc-Ueis) = 0.03 (U-B)eis
(Bjc-Beis) = 0.37 (B-V)eis
(Vjc-Veis) = -0.17 (B-V)eis
(Rjc-Reis) = -0.03 (V-R)eis
(Ijc-Ieis) = 0.19 (R-I)eis
```

Note that to apply the colour terms, one needs to operate not just with a single catalog column, but with 2 magnitude columns. e.g. the Ujc (Johnson U) value depends on the both the U_eis and B_eis value.

This has implications for re-extracted catalogs, where if one band was re-extracted, then strictly, to re-compute it's flux, then other bands must also be re-extracted and colour terms applied.

Because of this difficulty, and because there are currently no mechanisms for manipulating the columns (in vizier or aladin) in this way, we are treating the EIS Vega system magnitudes as if they are Johnson magnitudes.

How much difference will it make ? Following is an estimate of the magnitude offsets using [min,max] colours of EIS catalog:

```
(U-B) ~ [-2,2]    => Ujc = Ueis + [-0.06,0.06]
(B-V) ~ [-0.5,1.5] => Bjc = Beis + [0.19, 0.55]
                    => Vjc = Veis + [-0.26, 0.09]
(V-R) ~ [-1,2]   => Rjc = Reis + [-0.06,0.03]
(R-I) ~ [-1,2]   => Ijc = Ieis + [-0.19, 0.38]
```

6. Appendix 1. Instrumental Zero Points of GOODS data.

EIS WFI image	ZP	ZP_ERR
U' deep2c_FUp_2001-03-02T13:34:27.SCIENCE.fits	21.63198	0.083
U deep2c_FU_2001-03-02T13:30:45.SCIENCE.fits	21.35079	0.083
B deep2c_FB_2001-03-01T09:41:49.SCIENCE.fits	24.29485	0.029
V deep2c_FV_2001-03-01T09:54:17.SCIENCE.fits	23.92111	0.066
R deep2c_FR_2001-03-01T09:50:01.SCIENCE.fits	24.24464	0.048
I deep2c_FI_2001-03-01T09:45:54.SCIENCE.fits	23.16387	0.044

GOODS VLT-ISAAC image	field	ZP	ZP_ERR
J:			
EIS.2002-04-09T16:58:15.770.fits	J GOODS_9	25.142	-1
EIS.2002-04-09T16:58:18.670.fits	J GOODS_14	25.134	-1
EIS.2002-04-09T16:58:21.380.fits	J GOODS_20	25.195	-1
EIS.2002-04-09T16:58:24.040.fits	J GOODS_21	25.14	-1
EIS.2002-04-09T16:58:26.770.fits	J GOODS_10	25.048	-1
EIS.2002-04-09T16:58:29.960.fits	J GOODS_11	25	-1
EIS.2002-04-09T16:58:33.100.fits	J GOODS_15	25.063	-1
EIS.2002-04-09T16:58:35.660.fits	J GOODS_16	24.702	-1
Mean		25.178	
H:			
EIS.2002-04-09T16:58:39.120.fits	H GOODS_9	24.876	-1
EIS.2002-04-09T16:58:42.170.fits	H GOODS_10	24.596	-1
EIS.2002-04-09T16:58:45.530.fits	H GOODS_11	24.657	-1
EIS.2002-04-09T16:58:49.130.fits	H GOODS_14	24.676	-1
EIS.2002-04-09T16:58:52.540.fits	H GOODS_15	24.887	-1
EIS.2002-04-09T16:58:55.750.fits	H GOODS_16	24.646	-1
EIS.2002-04-09T16:58:58.950.fits	H GOODS_20	24.66	-1
EIS.2002-04-09T16:59:02.760.fits	H GOODS_21	24.671	-1
Mean		24.71	

K:

EIS.2002-04-09T16:59:08.470.fits	Ks	GOODS_9	24.223	-1
EIS.2002-04-09T16:59:14.070.fits	Ks	GOODS_14	24.313	-1
EIS.2002-04-09T16:59:18.450.fits	Ks	GOODS_20	24.236	-1
EIS.2002-04-09T16:59:21.380.fits	Ks	GOODS_21	24.203	-1
EIS.2002-04-09T16:59:25.970.fits	Ks	GOODS_10	24.095	-1
EIS.2002-04-09T16:59:29.570.fits	Ks	GOODS_11	24.268	-1
EIS.2002-04-09T16:59:33.980.fits	Ks	GOODS_15	24.1	-1
EIS.2002-04-09T16:59:36.940.fits	Ks	GOODS_16	23.64	-1
Mean			24.13	

GOODS NTT-SOFI image	field	ZP	ZP_ERR
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J:

deep2c_11_FJ_2001-02-15T18:47:48.fits	J	deep2c-1-1	23.0121	0.026
deep2c_12_FJ_2001-02-15T18:47:58.fits	J	deep2-1-2	22.8659	0.023
deep2c_13_FJ_2001-02-15T18:48:10.fits	J	deep2-1-1	22.8855	0.027
deep2c_14_FJ_2001-02-15T18:48:20.fits	J	deep2c-1-4	23.0264	0.032
deep2c_21_FJ_2001-02-15T18:48:31.fits	J	deep2c-2-1	23.0698	0.032
deep2c_24_FJ_2001-02-15T18:48:42.fits	J	deep2c-2-4	23.0264	0.03
deep2c_31_FJ_2001-02-15T18:48:53.fits	J	deep2c-3-1	23.0662	0.032
deep2c_34_FJ_2001-02-15T18:49:07.fits	J	deep2c-3-4	23.0324	0.03
deep2c_41_FJ_2001-02-15T18:49:18.fits	J	deep2c-4-1	23.0595	0.032
deep2c_42_FJ_2001-02-15T18:49:35.fits	J	deep2c-4-2	23.0224	0.026
deep2c_43_FJ_2001-02-15T18:49:48.fits	J	deep2-2-1	22.9323	0.016
Mean			22.9987	

K:

deep2c_11_FK_2001-02-15T18:47:54.fits	Ks	deep2c-1-1	22.2209	0.02
deep2c_12_FK_2001-02-15T18:48:04.fits	Ks	deep2-1-2	22.2064	0.02
deep2c_13_FK_2001-02-15T18:48:15.fits	Ks	deep2-1-1	22.2122	0.026
deep2c_14_FK_2001-02-15T18:48:25.fits	Ks	deep2c-1-4	22.2566	0.025
deep2c_21_FK_2001-02-15T18:48:36.fits	Ks	deep2c-2-1	22.2528	0.03
deep2c_24_FK_2001-02-15T18:48:47.fits	Ks	deep2c-2-4	22.2064	0.025
deep2c_31_FK_2001-02-15T18:48:59.fits	Ks	deep2c-3-1	22.2477	0.025
deep2c_34_FK_2001-02-15T18:49:13.fits	Ks	deep2c-3-4	22.2492	0.029
deep2c_41_FK_2001-02-15T18:49:26.fits	Ks	deep2c-4-1	22.2254	0.025
deep2c_42_FK_2001-02-15T18:49:43.fits	Ks	deep2c-4-2	22.223	0.02
deep2c_43_FK_2001-02-15T18:49:54.fits	Ks	deep2-2-1	22.2219	0.026
deep2c_44_FK_2001-02-15T18:49:59.fits	Ks	deep2c-4-4	22.228	0.029
Mean			22.23	

HST-ACS photometry

EPOCH	FILTER	PHOTFLAM	PHOTZPT	PHOTPLAM	PHOTBW
1	F435W	3.1818242E-19	-21.1	4311.8057	296.72891
1	F775W	1.1242358E-19	-21.1	7697.7715	436.8833
1	F606W	8.6088286E-20	-21.1	5922.3179	667.59766
1	F850LP	1.4748537E-19	-21.1	9130.6133	587.49323
2,3	F775W	1.0041268E-19	-21.1	7697.3428	434.50055
2,3	F606W	7.7792272E-20	-21.1	5915.3765	668.8573
2,3	F850LP	1.4196345E-19	-21.1	9103.2998	576.97607

Notes obtained from STScI web pages:

- a) The zeropoints in ST mags are derived from
 $m = -2.5 \log_{10}(\text{photflam}) + \text{PHOTZPT}$
and are based on constant flux density per unit wavelength
(and thus result in constant magnitudes for spectra having
constant flux per unit wavelength). PHOTZPT is always -21.1.

- b) PHOTFLAM is a conversion from DN to F_lambda:
i.e the units of PHOTFLAM are: $\text{erg} \cdot \text{cm}^{-2} \cdot \text{Angstrom}^{-1} \cdot \text{DN}^{-1}$