

# IVOA Spectral Models and Access in the Era of Big Data

**Vandana Desai**

Caltech/NASA-IPAC Infrared Science Archive

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Tim Brooke | Gregory Dubois-Felsmann | Steve Groom | Justin Howell |  
Emmanuel Joliet | Joe Mazzarella | Xiuqin Wu





## Abstract

We discuss the suitability of the IVOA Spectral Data Model for supporting common science use cases involving 1-D spectra and Spectral Energy Distributions (SEDs). We will describe our experiences in using this data model for spectra from Spitzer, SOFIA, and Herschel; and for SEDs from NED. We recommend some updates to the model based on this experience. We also present some science use cases that may strain the capabilities of the Simple Spectral Access protocol, including usage of “Big Spectra” data sets from e.g. Euclid and SPHEREx. Finally, we strongly advocate for the prioritization of work on the Spectral Data Model and spectral access in light of upcoming missions.



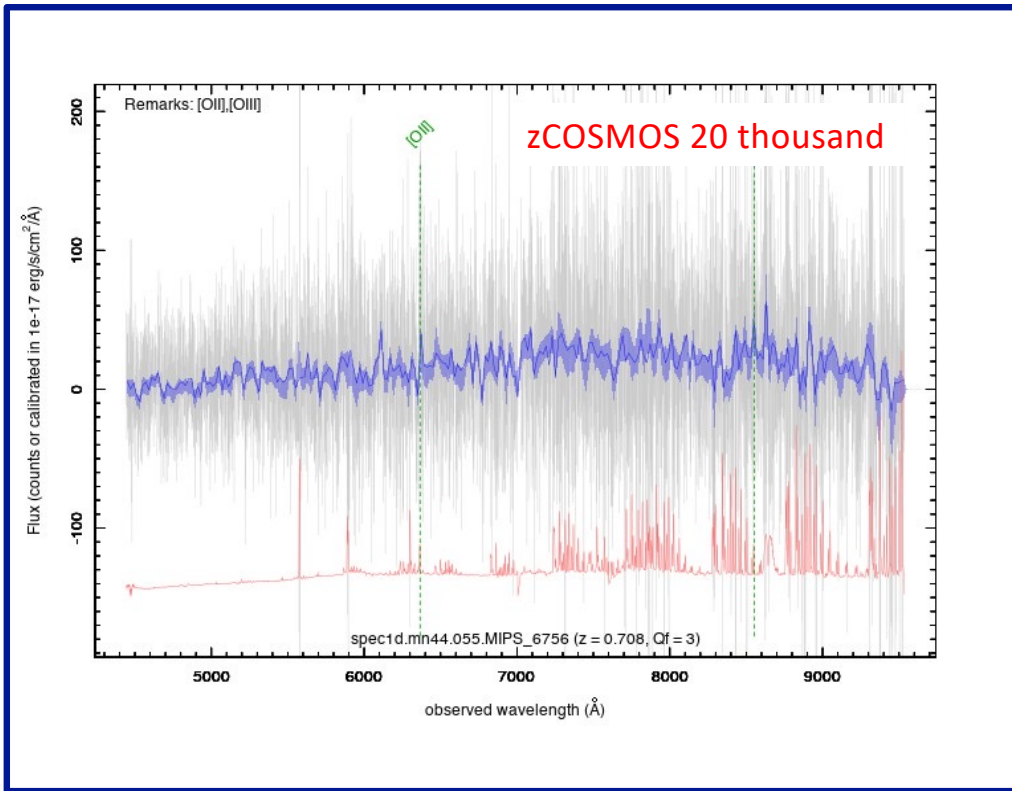
## Current State of Spectral Data Model

- Most recent approved version: v1.1 (2011)
  - “This data model may be used to represent spectra, time series data, segments of SED (Spectral Energy Distributions) and other spectral or temporal associations.”
- Most recent proposed recommendation: v2.0 (2016)
  - “Work on this Data model has concluded. . . . it is expected that the Spectral model will be revisited, possibly expanding the scope to cover other products such as Eschelle spectra and TimeSeries.”
- We started with the most recent approved version rather than the abandoned v2.0.
  - In Nov 2020, we presented a preliminary assessment of the DM against common use cases. Since then, we’ve developed against the model and recommended changes.

Title	Most stable	In progress	Version history										
Spectral <b>DM</b> - IVOA Spectral Data Model	1.1		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.1	1.1
			1.1	1.03	1.02	1.01	1.01	1.01	1.01	1.01	1.00		

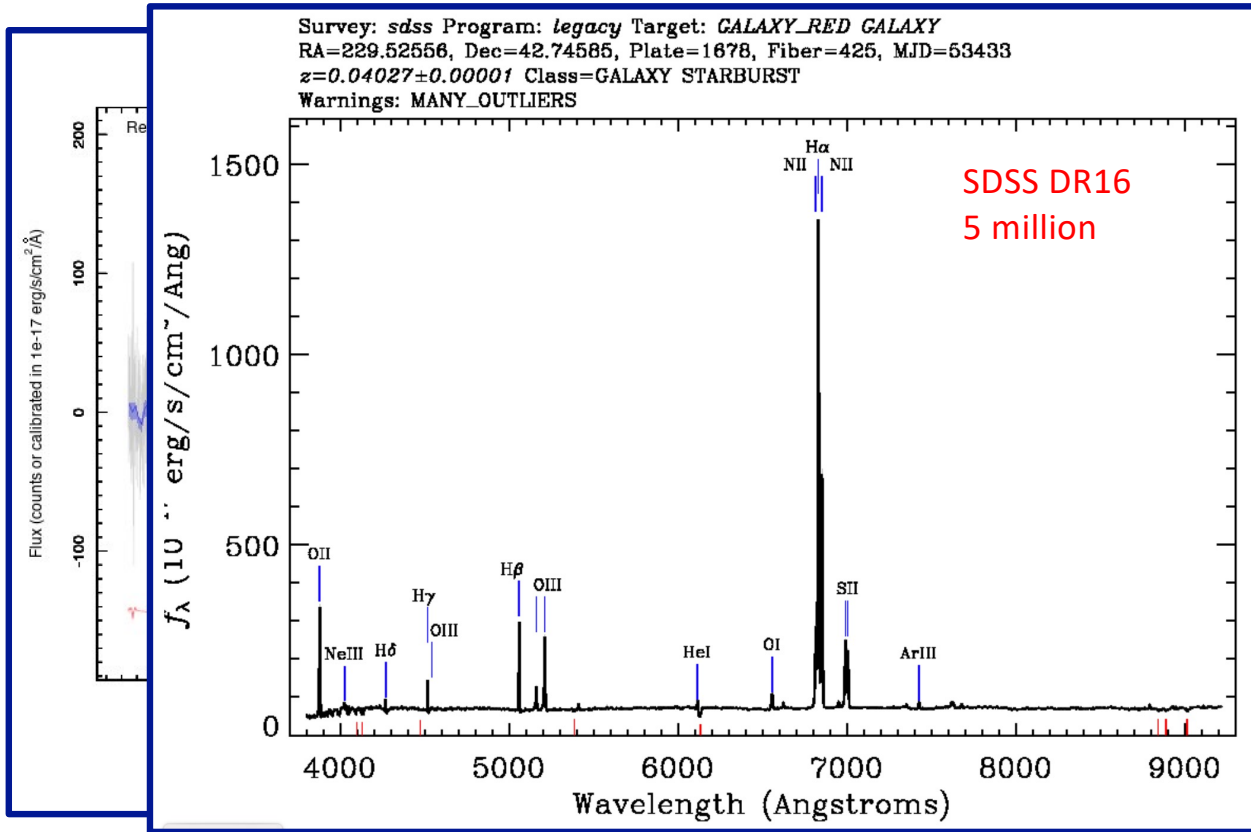


It is timely to assess IVOA spectral model and access





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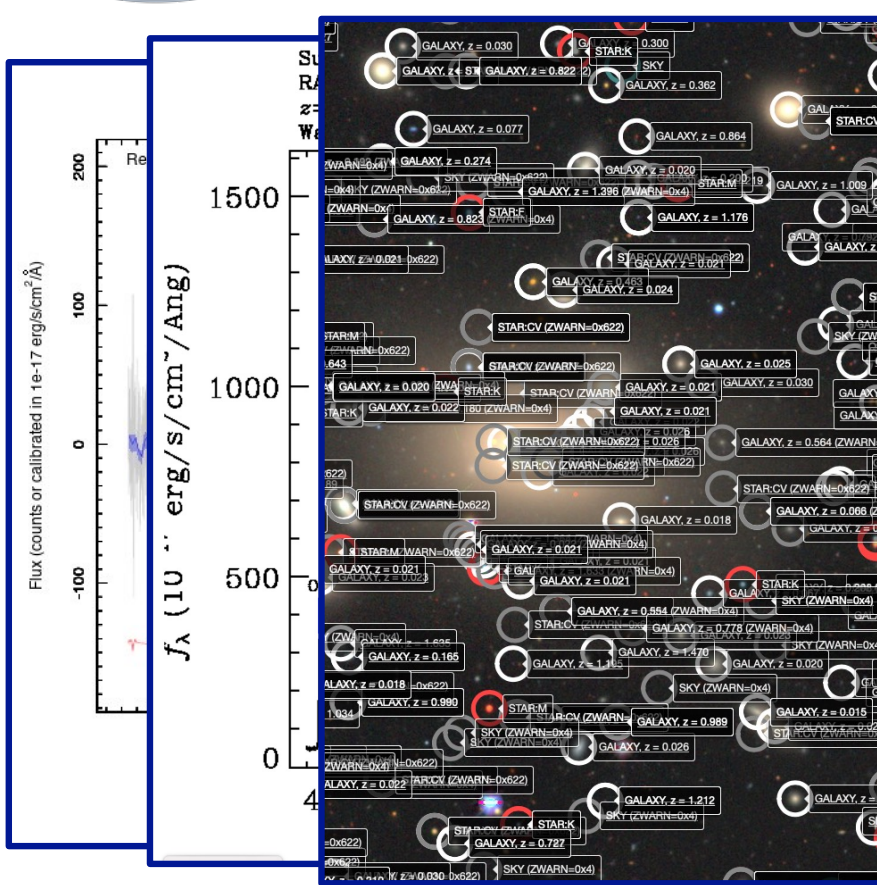










It is timely to assess IVOA spectral model and access

50 million  
**euclid**



>1 billion  
**SPHERE<sup>X</sup>**

And many more!

Caltech



How can we help archival re-users of existing spectral holdings?

1. Make it easy to quickly browse high level products (e.g. 1-D spectra) to assess science suitability
2. Make it easy to view spectra in the context of SEDs and other spectra

How can the spectral data model support these capabilities?





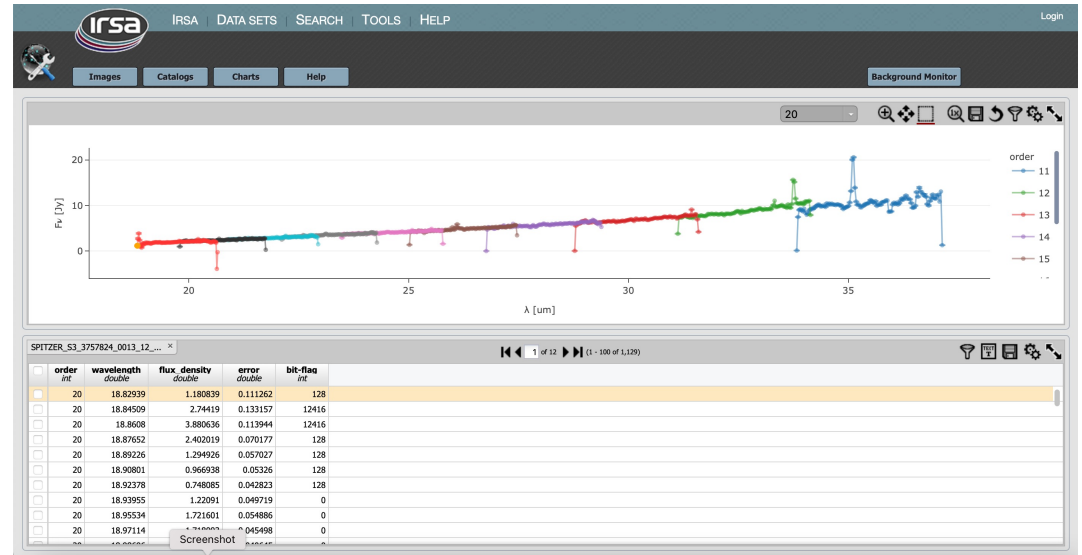
## How Spectral DM enables Firefly visualization capabilities

Implemented In Firefly?	Visualization Capability	Enabling Spectral DM v1.1 Component
✓	Recognize a spectrum or SED	<ul style="list-style-type: none"><li>Table utype = spec:Spectrum</li></ul>
✓	Plot the spectrum or SED (e.g. flux versus observed wavelength)	<ul style="list-style-type: none"><li>Column utype = spec:Spectrum.Data.SpectralAxis</li><li>Column utype = spec:Spectrum.Data.FluxAxis</li></ul>
✓	Include error bars in the plot	<ul style="list-style-type: none"><li>Column utype = spec:Spectrum.Data.FluxAxis.Accuracy.StatError</li></ul>
✓	Plot bandpass widths for SEDs	<ul style="list-style-type: none"><li>Column utype = spec:Spectrum.Data.SpectralAxis.Accuracy.BinLow</li><li>Column utype = spec:Spectrum.Data.SpectralAxis.Accuracy.BinHigh</li></ul>
✓	Plot spectral orders	Proposed change to SDM1.1 on separate slide
✓	Plot limits for SEDs	Proposed change to SDM1.1 on separate slide



# Proposed Changes to SDM1.1 to Plot Spectral Orders

- 1-D spectra from Spitzer's Infrared Spectrograph have multiple spectral orders
  - Spectral orders can overlap in wavelength
  - Plotting a Spitzer spectrum without accounting for orders gives you a mess
- Option 1: Create separate tables for each order
  - Requires plotting multiple tables on one chart
  - Additional development requirement
- Option 2: Treat order as a column
  - Column-based plotting is common
  - UCD="instr.order" already exists
  - We propose column utype = spec:Spectrum.Data.SpectralAxis.Order



Firefly-based IRSA Viewer tool shows multi-order Spitzer spectrum as a chart (top) and a table (bottom). Both are interactive.

Since our proposed column utype for spectral orders has not yet been accepted by the IVOA, this implementation recognizes ipac:Spectrum.Data.SpectralAxis.Order



# Proposed Changes to SDM1.1 to Plot Spectral Orders

**Table Options** Page Size:

Show:  Units  Data Type  Filters

Column Options | Advanced Filter | Table Meta

<input checked="" type="checkbox"/>	name	filter	type	units	utype	UCD
<input type="checkbox"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
<input checked="" type="checkbox"/>	order	<input type="text"/>	int		ipac:Spectrum.Data.SpectralAxis.Order	instr.order
<input checked="" type="checkbox"/>	wavelength	<input type="text"/>	double	um	spec:Spectrum.Data.SpectralAxis.Value	em.wl
<input checked="" type="checkbox"/>	flux_density	<input type="text"/>	double	Jy	spec:Spectrum.Data.FluxAxis.Value	phot.flux.density;em.freq
<input checked="" type="checkbox"/>	error	<input type="text"/>	double	Jy	spec:Spectrum.Data.FluxAxis.Accuracy.StatError	stat.error;phot.flux.density;em.freq
<input checked="" type="checkbox"/>	bit-flag	<input type="text"/>	int		spec:Spectrum.Data.FluxAxis.Quality	

Utypes and UCDs that were used to produce the plot on the previous slide.



# Proposed Changes to SDM1.1 to Plot Spectral Orders

**Table Options**

Show:  Units  Data Type  Filters

**Column Options**    Advanced Filter    Table Meta

<input checked="" type="checkbox"/>	name	filter	type	units	utype
<input checked="" type="checkbox"/>	order		int		ipac:Spectrum.Data.SpectralAxis.Order
<input checked="" type="checkbox"/>	wavelength		double	um	spec:Spectrum.Data.SpectralAxis.Value
<input checked="" type="checkbox"/>	flux_density		double	Jy	spec:Spectrum.Data.FluxAxis.Value
<input checked="" type="checkbox"/>	error		double	Jy	spec:Spectrum.Data.FluxAxis.Accuracy.
<input checked="" type="checkbox"/>	bit-flag		int		spec:Spectrum.Data.FluxAxis.Quality

**Plot Parameters**

Add New Chart     Modify Trace

Choose Trace: 20

Spectral axis column(X): wavelength

Spectral axis units: um

Flux axis column(Y): flux\_density

Error: Symm    error

Flux axis units: Jy

Trace Style: connected points

▶ Trace Options

▶ Chart Options

Apply    Close

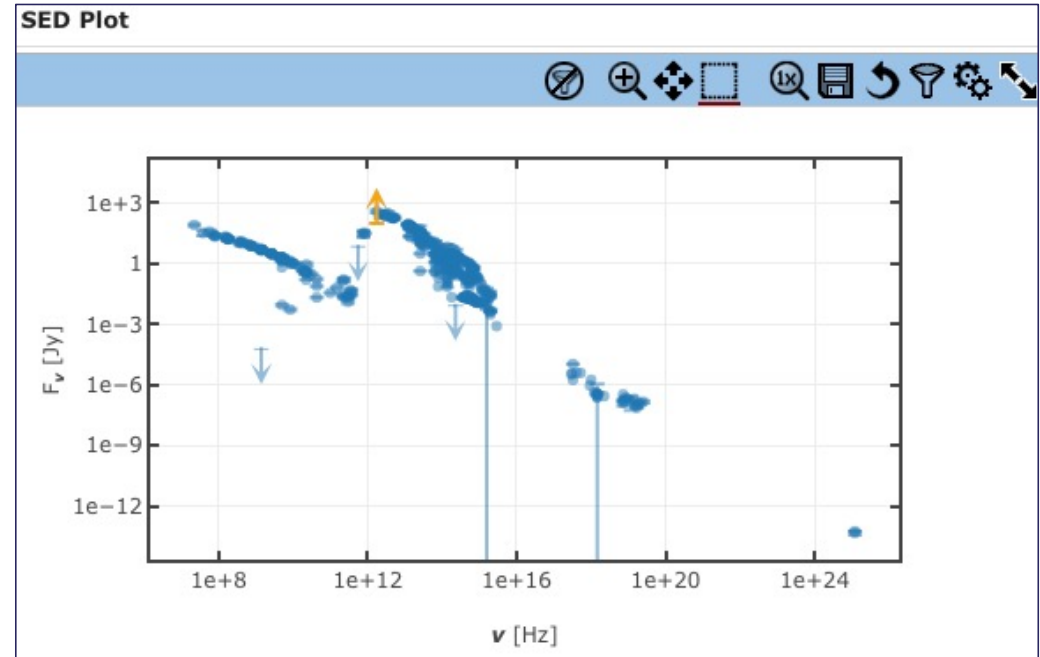
Plot parameters allow user to change units based on data model.





## Proposed changes to SDM1.1 to plot limits for SEDs (1/2)

- Spectral Energy Distributions (SEDs) often include limits on measurements.
  - These can be upper or lower limits
  - Plotters need to indicate limits clearly to avoid scientific misunderstanding
- SDM1.1 handling of upper limits is not ideal
  - Upper limits are to be represented as measurements with highly asymmetric errors
  - Example: upper limit of  $f$ 
    - flux =  $f$
    - lower statistical error =  $f$
    - upper statistical error = 0
  - This would lead to the display of an error bar extending from 0 to the upper limit (maybe ok for our purposes)
  - Mathematically incorrect
- SpectrumDM 1.1 does not address lower limits
  - Lower limits do appear in some NED datasets
  - Saturation, edge effects

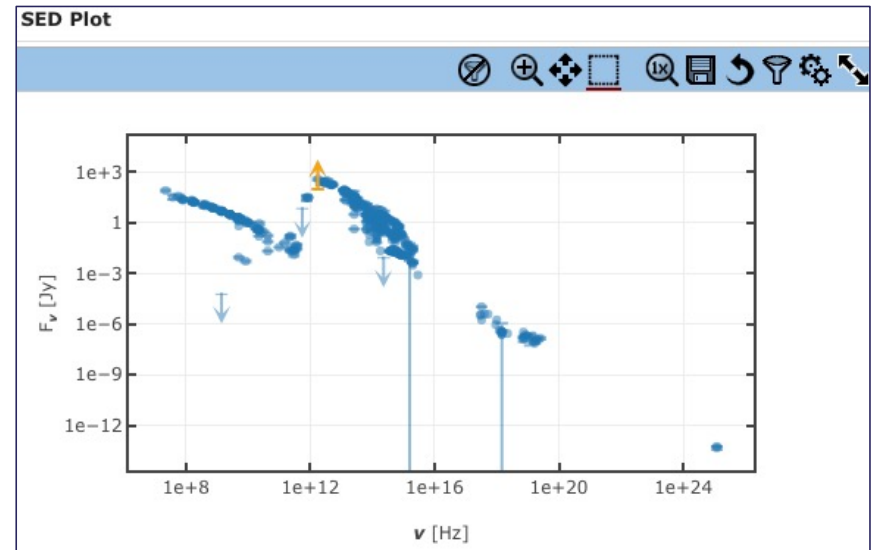


Firefly-based NED web GUI shows NED SED with upper and lower limits.



## Proposed changes to SDM1.1 to plot limits for SEDs (1/2)

- Proposal: Combine new utypes with existing UCDs
- Upper limit column utype = `spec:Spectrum.Data.FluxAxis.Accuracy.UpperLimit`
- Lower limit column utype = `spec:Spectrum.Data.FluxAxis.Accuracy.LowerLimit`



Firefly-based NED web GUI shows NED SED with upper and lower limits.

Since our proposed column utypes for limits have not yet been accepted by the IVOA, this implementation recognizes

- Column utype = `ipac:Spectrum.Data.FluxAxis.Accuracy.UpperLimit`
- Column utype = `ipac:Spectrum.Data.FluxAxis.Accuracy.LowerLimit`



## Future Considerations

Visualization Capability	Considerations
Label the plot with units	<ul style="list-style-type: none"><li>SDM1.1 specifies OGIP unit convention rather than VOUnit, which was established in 2014.</li><li>Is there any reason <i>not</i> to change to VOUnit?</li></ul>
Change units	
Download many thousands of spectra	<ul style="list-style-type: none"><li>FITS representation is more efficient than VOTable for many spectra</li><li>Look to Euclid</li></ul>
Correct axes for redshift	<ul style="list-style-type: none"><li>All of these require assembling data that may exist outside of the spectrum.</li></ul>
Label possible spectral features	
Label measured spectral features	
Overplot spectral response or atmospheric transmission curves	
Overplot synthetic photometry	<ul style="list-style-type: none"><li>Spitzer IRS Enhanced Data Products provide synthetic photometry within the spectral file. How should this be represented?</li><li>Very important to distinguishing synthetic versus real photometry</li></ul>



## Summary

- In Nov 2020, we presented an initial assessment of SDM1.1 against science-driven 1-D spectrum visualization requirements
- We have completed a “phase 1” implementation of a 1-D spectral viewer in the open-source Firefly visualization toolkit
- We found that SDM1.1 does not adequately support two required capabilities:
  - Plotting spectral orders
  - Plotting upper and lower limits for SEDs
- We intend to formally recommend the addition of 3 new column utypes to SDM1.1
  - column utype = `spec:Spectrum.Data.SpectralAxis.Order`
  - column utype = `spec:Spectrum.Data.FluxAxis.Accuracy.UpperLimit`
  - column utype = `spec:Spectrum.Data.FluxAxis.Accuracy.LowerLimit`
- We have more capabilities to implement. Expect another talk!