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EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

# HSC Workflow Using VO-DML

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Example Science Workflow for Hubble Source Catalog

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## Perform a Hubble Source Catalog Cone Search

- Results are “matches”, i.e., a cross-correlation of one or more source detections.

13 Total Rows      MESSIER 082, radius: 0.00100°      Footprints: All

**Filters**      **List of Objects**

Clear Filters   Edit Filters...   Help...

**Keyword/Text Filter**

Filter All Columns

**AbsCorr**

Name      Quantity

Y      (10 of 10)

N      (3 of 3)

**Target Name**

Name      Quantity

NGC3034      (5 of 5)

NGC3034-OUTFLOW      (4 of 4)

NGC3034B-2      (3 of 3)

3C231.0      (1 of 1)

**Match ID (none)**

17109570      17350615

Zoom to Range      Reset/Unzoom

**List of Objects**

Edit Columns...   Table Display: All

	Actions	Match ID	Distance	Match RA	Match Dec	DSigma
<input type="checkbox"/>		17350576	0.0138532926726087	09:55:52.842	+69:40:45.20	0
<input type="checkbox"/>		17114343	0.0179429551355409	09:55:52.582	+69:40:44.99	0
<input type="checkbox"/>		17112744	0.0191552765735947	09:55:52.559	+69:40:46.52	24.93527552
<input type="checkbox"/>		17350615	0.0258641255539858	09:55:52.532	+69:40:46.95	0
<input type="checkbox"/>		17113661	0.0267433853887595	09:55:52.907	+69:40:47.06	0
<input type="checkbox"/>		17109570	0.0444490638851655	09:55:53.163	+69:40:47.16	0
<input type="checkbox"/>		17115228	0.0446758577527783	09:55:52.484	+69:40:48.13	0
<input type="checkbox"/>		17111544	0.0476439565040232	09:55:52.177	+69:40:45.67	0
<input type="checkbox"/>		17114358	0.0522595707460514	09:55:53.160	+69:40:47.94	90.73241695
<input type="checkbox"/>		17114183	0.0536607917348293	09:55:52.108	+69:40:45.92	0
<input type="checkbox"/>		17111787	0.0577374777259268	09:55:52.518	+69:40:49.06	124.6352286
<input type="checkbox"/>		17109683	0.0582370666048446	09:55:52.406	+69:40:48.84	0
<input type="checkbox"/>		17110937	0.0588629132934098	09:55:52.954	+69:40:49.09	0

10:08:56.134 +66:23:48.37      RA DEC  
09:55:52.726 +69:40:45.77      hhmmss/deg



## Choose a match of interest

- Of matches observed in multiple filters, choose one with brightest B magnitude.

	Actions	Match ID	Match RA	Match Dec	Num Filters	W2_F336W	W2_F439W	W2_F502N	W2_F547M	W2_
1		17112744	09:55:52.559	+69:40:46.52	5	NaN	NaN	19.60960006...	19.14710044...	NaN
2		17114358	09:55:53.160	+69:40:47.94	5	NaN	NaN	19.21360015...	18.94580078...	NaN
3		17111787	09:55:52.518	+69:40:49.06	5	NaN	NaN	NaN	20.57239913...	21.6
4		17109683	09:55:52.406	+69:40:48.84	3	NaN	22.99469947...	NaN	NaN	20.3
5		17115228	09:55:52.484	+69:40:48.13	2	NaN	23.68339920...	NaN	NaN	21.4
6		17114183	09:55:52.108	+69:40:45.92	2	NaN	NaN	NaN	NaN	NaN
7		17350576	09:55:52.842	+69:40:45.20	1	20.76779937...	NaN	NaN	NaN	NaN
8		17114343	09:55:52.582	+69:40:44.99	1	20.39450073...	NaN	NaN	NaN	NaN
9		17350615	09:55:52.532	+69:40:46.95	1	21.71129989...	NaN	NaN	NaN	NaN
10		17113661	09:55:52.907	+69:40:47.06	1	NaN	NaN	NaN	NaN	NaN
11		17109570	09:55:53.163	+69:40:47.16	1	20.52269935...	NaN	NaN	NaN	NaN
12		17111544	09:55:52.177	+69:40:45.67	1	NaN	NaN	NaN	NaN	NaN
13		17110937	09:55:52.954	+69:40:49.09	1	20.83860015...	NaN	NaN	NaN	NaN



## Load all the detections for chosen match

- Each detection was extracted from an image.
- Cutouts around match are shown.

The screenshot displays a software interface with a table titled "List of Measurements" and a corresponding astronomical image. The table has columns for Actions, Preview, CatID, MatchID, Instrument, Filter, and MagAper2. Three rows of data are visible, each with a preview image and a set of action icons. The astronomical image on the right shows a field of stars with a red dashed circle highlighting a specific match. The image also displays RA and DEC coordinates in the top right corner.

Actions	Preview	CatID	MatchID	Instrument	Filter	MagAper2
		266224460	17109683	WFPC2	F439W	22.9946994
		268051527	17109683	WFPC2	F555W	20.3750991
		257567359	17109683	WFPC2	F814W	18.8915004



Data Provider – Use VO-DML mapping to describe sources

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## Map Source model instances into the HSC VOTable

●	<<objectType>>	●
●	source:Source	●
	- PRIMARYKEY : vo-dml:Identifier [0..1]	●
	- CONTAINER : source:Catalogue [0..1]	●
	- name : ivoa:string [0..1]	●
	- classification : ivoa:string [0..1]	●
	- luminosity : source:LuminosityMeasurement [0..-1]	●
	- position : source:SourcePosition [1..-1]	●

●	VOTABLE_3::TABLE_1
●	- MatchID : long
●	- Distance : double
●	- MatchRA : double
●	- MatchDec : double
●	- DSigma : double
●	- AbsCorr : char
●	- NumFilters : int
●	- NumVisits : int
●	- NumImages : int
●	- StartMJD : double
●	- StopMJD : double
●	- TargetName : char
●	- CI : double
●	- CI_Sigma : double
●	- KronRadius : double
●	- KronRadius_Sigma : double
●	- Extinction : double
●	- SpectrumFlag : char
●	- A_F435W : double
●	- A_F435W_Sigma : double
●	- A_F435W_N : int



## Source.name is “MatchID” FIELD

●	<<objectType>> source:Source	●
●	- PRIMARYKEY : vo-dml:Identifier [0..1]	●
	- CONTAINER : source:Catalogue [0..1]	●
	- SAMEINSTANCE : vo-dml:ObjectInstance [0..1]	●
	- name : ivoa:string [0..1]	●
	- classification : ivoa:string [0..1]	●
	- luminosity : source:LuminosityMeasurement [0..-1]	●
	- position : source:SourcePosition [1..-1]	●

●	VOTABLE_3::TABLE_1
●	- MatchID : long
●	- Distance : double
●	- MatchRA : double
●	- MatchDec : double
●	- DSigma : double
●	- AbsCorr : char
●	- NumFilters : int





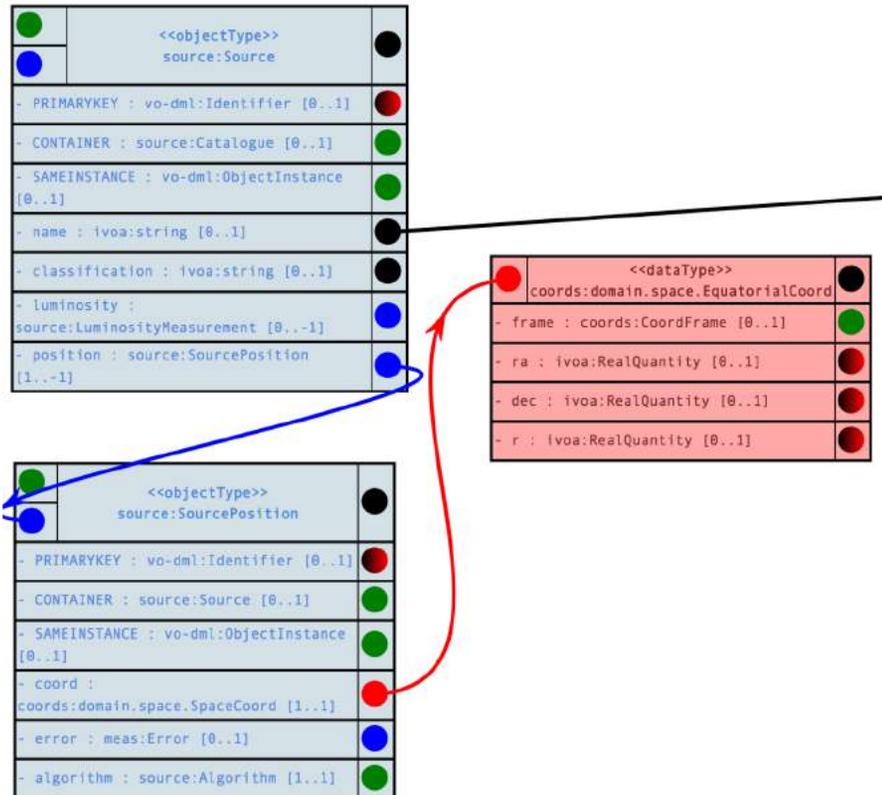
## Source has a SourcePosition

●	<<objectType>> source:Source	●
●	- PRIMARYKEY : vo-dml:Identifier [0..1]	●
	- CONTAINER : source:Catalogue [0..1]	●
	- SAMEINSTANCE : vo-dml:ObjectInstance [0..1]	●
	- name : ivoa:string [0..1]	●
	- classification : ivoa:string [0..1]	●
	- luminosity : source:LuminosityMeasurement [0..1]	●
	- position : source:SourcePosition [1..1]	●

●	<<objectType>> source:SourcePosition	●
●	- PRIMARYKEY : vo-dml:Identifier [0..1]	●
	- CONTAINER : source:Source [0..1]	●
	- SAMEINSTANCE : vo-dml:ObjectInstance [0..1]	●
	- coord : coords:domain:space.SpaceCoord [1..1]	●
	- error : meas:Error [0..1]	●
	- algorithm : source:Algorithm [1..1]	●

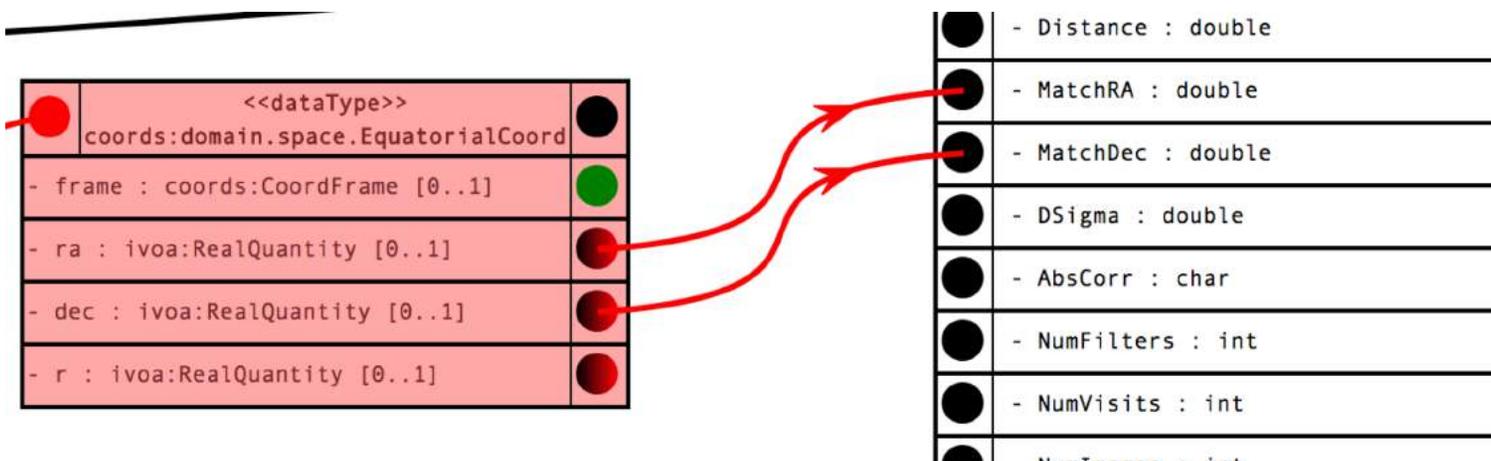


## SourcePosition has an EquatorialCoord



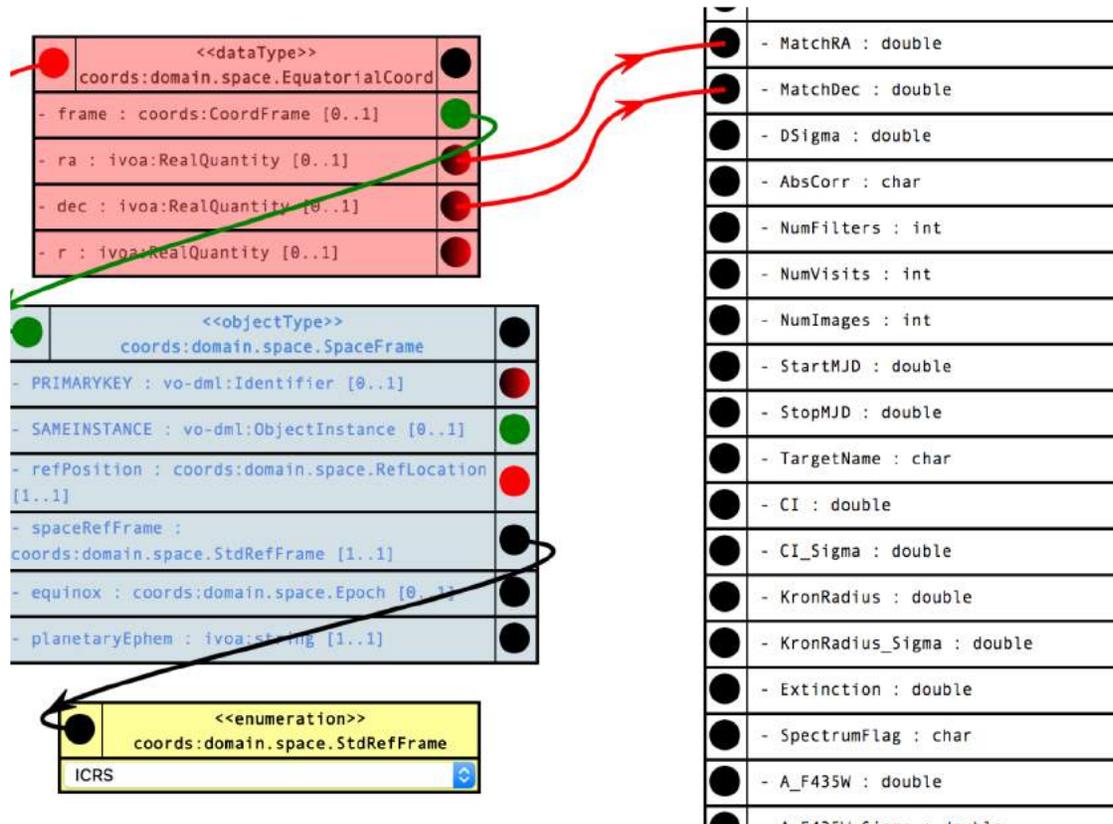


## Map the ra and dec to appropriate FIELDS



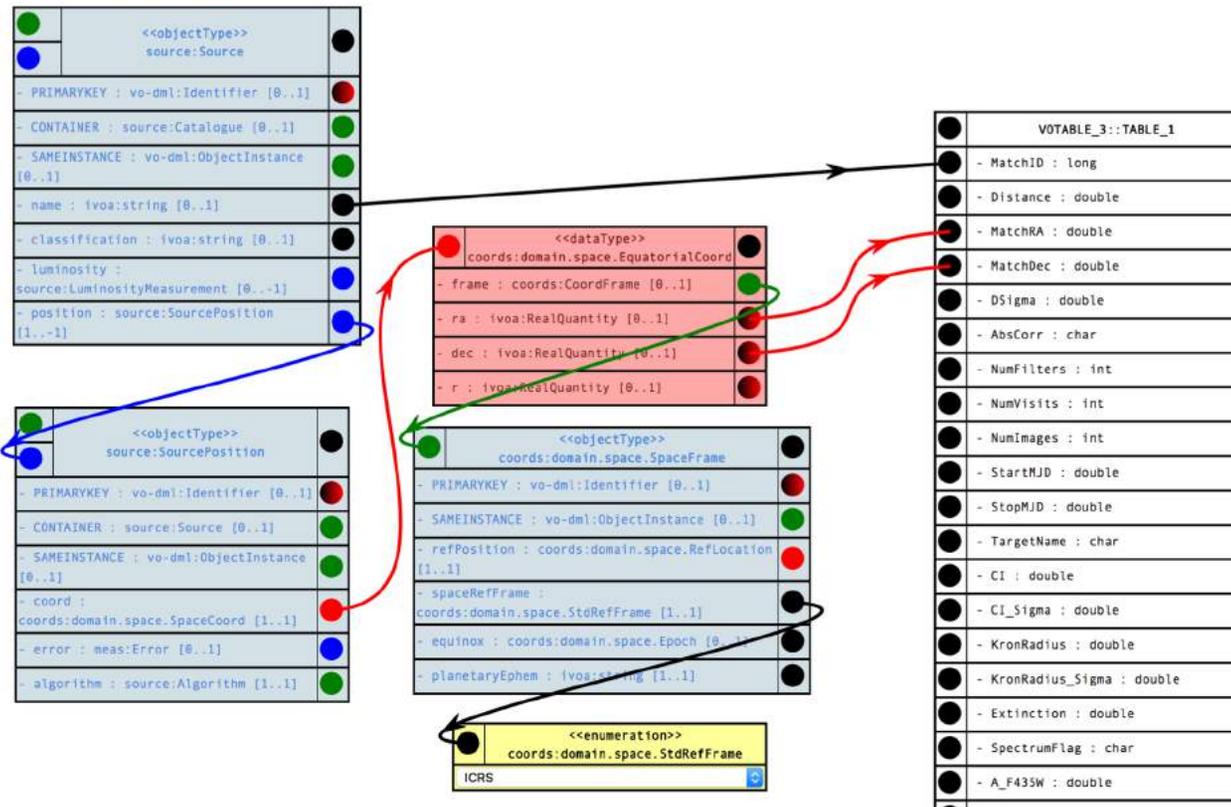


## Add the ICRS frame





## Complete mapping for name and position



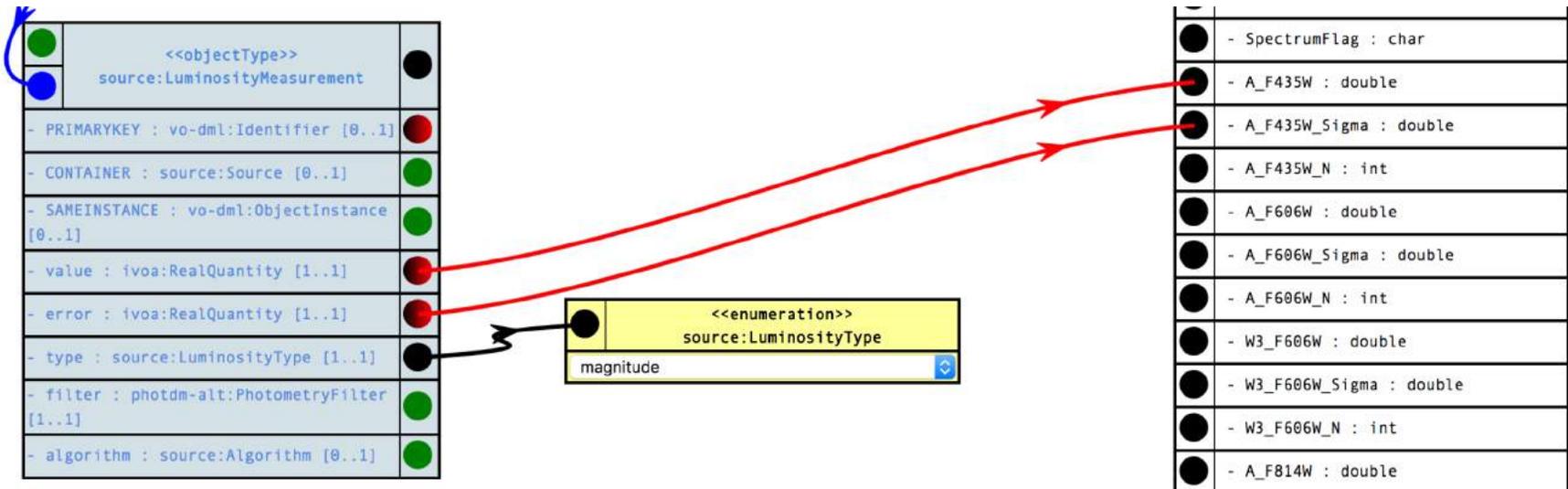


## Complete mapping for name and position - XML

```
<GLOBALS>
  <INSTANCE dmtype="coords:domain.space.SpaceFrame" ID="_icrs_">
    <ATTRIBUTE dmrole="coords:domain.space.SpaceFrame.spaceRefFrame">
      <LITERAL dmtype="coords:domain.space.StdRefFrame" value="ICRS"/>
    </ATTRIBUTE>
  </INSTANCE>
</GLOBALS>
<TEMPLATES tableref="matches">
  <INSTANCE dmtype="source:Source">
    <ATTRIBUTE dmrole="source:Source.name">
      <COLUMN dmtype="ivoa:string" ref="MatchID"/>
    </ATTRIBUTE>
    <COMPOSITION dmrole="source:Source.position">
      <INSTANCE dmtype="source:SourcePosition">
        <ATTRIBUTE dmrole="meas:CoordMeasure.coord">
          <INSTANCE dmtype="coords:domain.space.EquatorialCoord">
            <ATTRIBUTE dmrole="coords:domain.space.EquatorialCoord.ra">
              <COLUMN dmtype="ivoa:RealQuantity" ref="MatchRA"/>
            </ATTRIBUTE>
            <ATTRIBUTE dmrole="coords:domain.space.EquatorialCoord.dec">
              <COLUMN dmtype="ivoa:RealQuantity" ref="MatchDec"/>
            </ATTRIBUTE>
            <REFERENCE dmrole="coords:Coordinate.frame">
              <IDREF>_icrs_</IDREF>
            </REFERENCE>
          </INSTANCE>
        </ATTRIBUTE>
      </INSTANCE>
    </COMPOSITION>
  </INSTANCE>
</TEMPLATES>
```

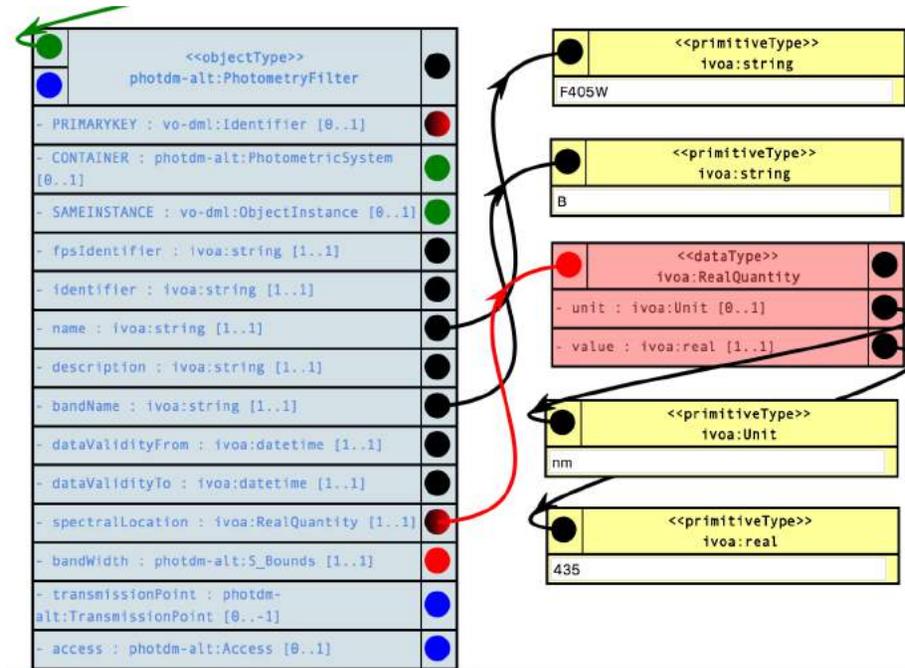


## Map the luminosities





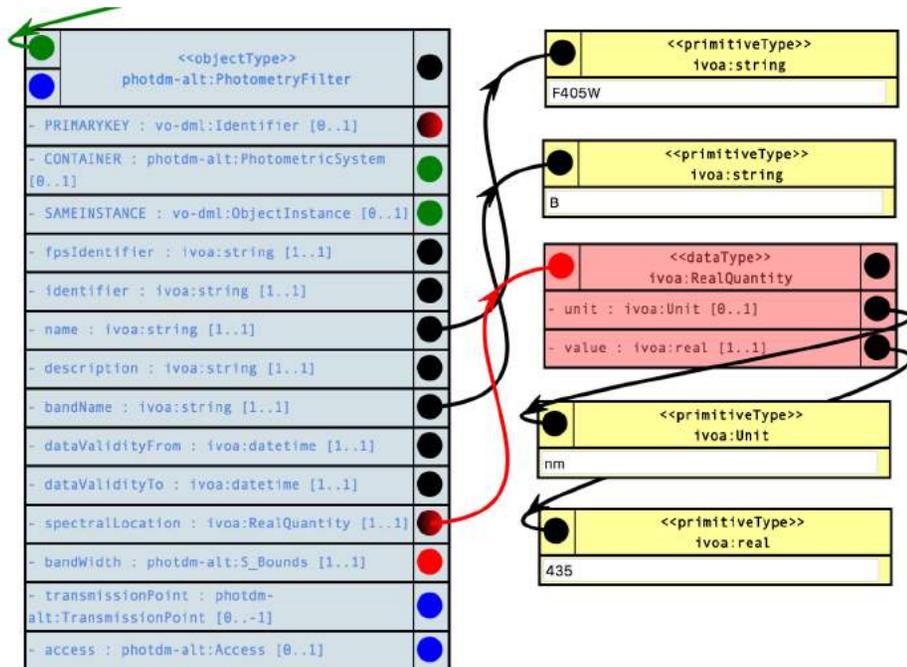
## Define the filters





## Define the filters

- This information was not in the original VOTable.
- By adding these filter instances, the VOTable becomes more informative.



```
<INSTANCE ID="A_F435W" dmtpe="photdm-alt:PhotometryFilter">
  <PRIMARYKEY>
    <PKFIELD>
      <LITERAL value="A_F435W" dmtpe="ivoa:string"/>
    </PKFIELD>
  </PRIMARYKEY>
  <ATTRIBUTE dmrole="photdm-alt:PhotometryFilter.name">
    <LITERAL value="A_F435W" dmtpe="ivoa:string"/>
  </ATTRIBUTE>
  <ATTRIBUTE dmrole="photdm-alt:PhotometryFilter.bandName">
    <LITERAL value="B" dmtpe="ivoa:string"/>
  </ATTRIBUTE>
  <ATTRIBUTE dmrole="photdm-alt:PhotometryFilter.spectralLocation">
    <LITERAL value="435" dmtpe="ivoa:RealQuantity"/>
  </ATTRIBUTE>
</INSTANCE>
```



## Add annotations to existing services

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Using these mapping techniques, VO-DML annotations were added to 2 MAST services:

- HSC Cone Search annotated with one Source instance per row:
  - [https://masttest.stsci.edu/vodml/Mashup/VoQuery.aspx/HscCone?RA=\[RA\]&DEC=\[Dec\]&SR=\[radius\]](https://masttest.stsci.edu/vodml/Mashup/VoQuery.aspx/HscCone?RA=[RA]&DEC=[Dec]&SR=[radius])
  - Each Source is a “match”, i.e., a cross-correlation of one or more source detections.
  - Each source has:
    - A MatchID identifying the match
    - One or more luminosities
- HSC Detection search annotated with one Detection per row:
  - [https://masttest.stsci.edu/vodml/Mashup/VoQuery.aspx/HscDetections?MATCHID=\[MatchID\]](https://masttest.stsci.edu/vodml/Mashup/VoQuery.aspx/HscDetections?MATCHID=[MatchID])
  - Each Detection has exactly one:
    - URL to the image from which the Detection was extracted
    - Luminosity, measured from the Detection’s image



## Data provider feedback

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- Creating annotations by hand was error prone for me.
  - Less so when I was more familiar with VO-DML models.
- With Mapper tool, annotation creation was a couple orders of magnitudes faster.
- For any annotations, validators will be very important.
- Existing VOTables don't always map cleanly to standard models.
  - Sometimes it may be worth tweaking the existing service to make the output fit the model a little better.
- Referencing global instances (like photometry filters) by values from the table data is supported, but details not obvious.

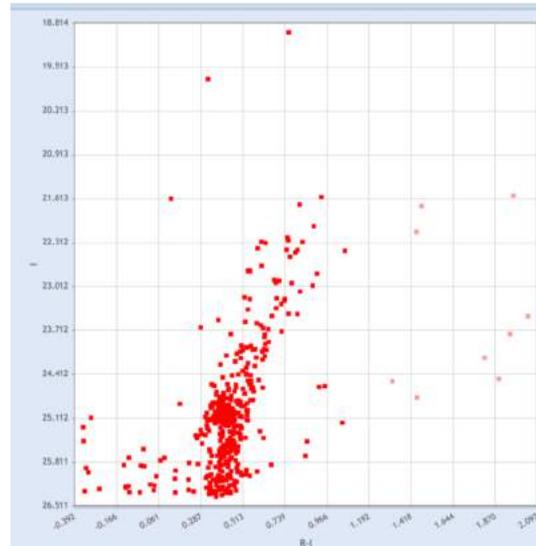
A deep space image of a nebula, likely the Carina Nebula, showing intricate structures of gas and dust in shades of blue, purple, and brown. The background is filled with a dense field of stars, many of which are bright blue. The text "Client understanding model instances" is centered in white, with a thin orange horizontal line below it.

Client understanding model instances



## MAST Portal recognizes the VO-DML objects

- \_\_dmtype\_\_:** [source:Source](#)
- \_\_id\_\_:** [\\_source](#)
- name:** 17112744
- luminosity**
  - 0**
    - \_\_dmtype\_\_:** [source:LuminosityMeasurement](#)
    - value**
    - error**
    - type:** magnitude
    - filter:** [W2\\_F336W](#)
  - 1**
    - \_\_dmtype\_\_:** [source:LuminosityMeasurement](#)
    - value**
    - error**
    - type:** magnitude
    - filter:** [W2\\_F439W](#)
  - 2**
    - \_\_dmtype\_\_:** [source:LuminosityMeasurement](#)
    - value:** 19.6096000671387
    - error**
    - type:** magnitude
    - filter:** [W2\\_F502N](#)
  - 3**
    - \_\_dmtype\_\_:** [source:LuminosityMeasurement](#)
    - value:** 19.1471004486084
    - error**
    - type:** magnitude
    - filter:** [W2\\_F547M](#)



- \_\_dmtype\_\_:** [photdm-alt:PhotometryFilter](#)
- \_\_id\_\_:** [\\_W2\\_F502N](#)
- \_\_primaryKey\_\_:** [W2\\_F502N](#)
- \_\_attributes\_\_**
  - name:** W2\_F502N
  - bandName:** V
  - spectralLocation:** 502



## Using Python to follow example workflow

---

- See notebook: <https://github.com/olaurino/ivoa-dm-examples/blob/master/notebooks/HSC-Example.ipynb>
- Perform a cone search which returns a VO-DML aware result.

```
def cone_search(base_url, coord: SkyCoord, radius):  
    # Make sure the coordinates are expressed in ICRS and degrees  
    ra = coord.icrs.ra.deg  
    dec = coord.icrs.dec.deg  
    # Make sure radius is in degrees  
    radius_deg = radius.to(u.deg).value  
  
    # Cone search params.  
    params = {'RA': ra, 'DEC': dec, 'SR': radius_deg}  
  
    return read_url(base_url, params)  
  
# Define Cone Search parameters  
search_coord = SkyCoord.from_name("m82")  
search_radius = 0.001 * u.deg  
  
# HSC Cone Base URL (in general could come from registry)  
HSC_MATCHES_URL = 'https://masttest.stsci.edu/vodml/Mashup/VoQuery.asmx/HscCone?'  
  
# Perform search. Result is VO-DML aware parser object.  
hsc_matches_results = cone_search(HSC_MATCHES_URL, search_coord, search_radius)
```



## Classic astropy table results are available.

```
# Get Astropy table representing the results
# kind of a hack, we need to improve the API
matches_table = list(hsc_matches_results.tables.values())[0]

# Show info
print(f'{source_template.cardinality} matches found.')
matches_table.show_in_notebook()
```

19 matches found.

QTable masked=True length=19

Show  entries Search:

idx	MatchID	Distance	MatchRA	MatchDec	DSigma	AbsCorr	NumFilters	NumVisits	NumImages	StartMJD	StopMJD
	none	arcminutes	deg	deg	mas					days	days
0	17350615.0	0.00883306720656974	148.96888203758	69.6797072526489	0.0	Y	1	1	1	54834.6258381181	54834.6575510763
1	17112744.0	0.0131180875647911	148.968997760412	69.6795900802937	24.9352755222915	Y	5	2	7	50523.2968749586	51053.1723864423
2	17115228.0	0.020600919203083	148.968682222876	69.6800372272498	0.0	N	2	1	2	50706.0557152592	50706.5385857429
3	17111544.0	0.0303987662778864	148.967404818518	69.6793523018495	0.0	Y	1	1	1	51053.0043308656	51053.0177567475
4	17109683.0	0.0319055670213261	148.968358648006	69.6802334322381	0.0	N	3	1	3	50706.0557152592	50706.5385857429
5	17114183.0	0.032588602427965	148.96711764508	69.6794230683398	0.0	Y	2	1	2	51053.0043308656	51053.0362752476



## Extract the Source instances

---

```
# By default tabular instances are described as "templates" that provide  
# access to individual columns. We'll assume there is only one Source template per row.  
source_template = hsc_matches_results.find_instances(Source)[0]  
  
# We can unroll the templates to get a list of Sources, one per row.  
sources = unroll(source_template)
```



## Demonstrate accessing Source attributes

---

```
def print_source_properties(source):
    name = int(source.name.value)
    sky_coord = source.position[0].coord
    print(f'\nSource {name}\nposition: {sky_coord}''')

    for luminosity in source.luminosity:
        band_name = luminosity.filter.band_name
        mag = luminosity.value.value if luminosity.type == 'magnitude' else np.nan
        if not np.isnan(mag):
            print(f'    {band_name} mag: {mag}, ')

for source in sources:
    print_source_properties(source)
```

```
Source 17111544
position: <SkyCoord (ICRS): (ra, dec) in deg
(148.96740482, 69.6793523)>
R mag: 19.2964992523193,
```

```
Source 17109683
position: <SkyCoord (ICRS): (ra, dec) in deg
(148.96835865, 69.68023343)>
B mag: 22.9946994781494,
V mag: 20.3750991821289,
I mag: 18.8915004730225,
```



## Using source attributes, various selections can be done

---

- Of sources with multiple luminosities, select the one with the brightest B magnitude.

```
def find_brightest(sources, band_name):  
    [snip...]  
  
brightest = find_brightest(sources, "B")  
print(int(brightest.name.value))
```

17109683



## Follow-up query to find all Detections for selected Source

- Follow-up query may be discoverable via Provenance or DataLink techniques?

```
HSC_DETECTIONS_BASE_URL = 'https://masttest.stsci.edu/vodml/Mashup/VoQuery.asmx/HscDetections?'
params = {'MATCHID': brightest.name.value}
detection_results = read_url(HSC_DETECTIONS_BASE_URL, params)

detection_template = detection_results.find_instances(Detection)[0]
print(f"{detection_template.cardinality} detections found")
detections = unroll(detection_template)

detections_table = list(detection_results.tables.values())[0]
detections_table.show_in_notebook()
```

3 detections found

*QTable masked=True length=3*

Show 50 entries Search:

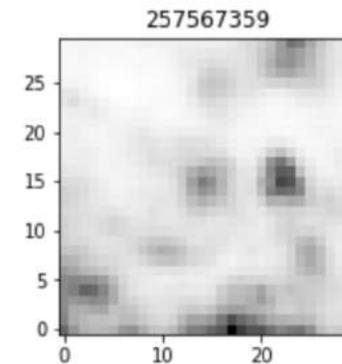
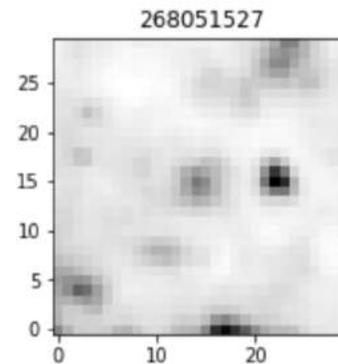
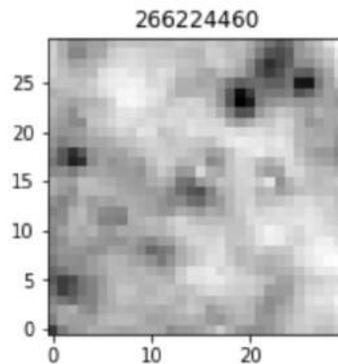
idx	CatID	MatchID	MemID	SourceID	ImageID	Det	MatchRA	MatchDec	SourceRA	SourceDec
				none	none		deg	deg	deg	deg
0	266224460	17109683	1	4662322165.0	550998.0	Y	148.968358648006	69.6802334322381	148.968358648006	69.6802334322381



## Access Detection images and plot cutouts around the Source

```
for idx, detection in enumerate(detections):  
    #Make the title be the name of the detection.  
    title = detection.name  
    ra = detection.position[0].coord.icrs.ra.deg  
    dec = detection.position[0].coord.icrs.dec.deg  
  
    # Plot the first image data we find.  
    filename = detection.source_image[0].url  
    download_and_plot_cutout(title, ra, dec, filename)
```

Cutouts





## Client development feedback

---

- Understanding VO-DML concepts was important for writing an effective parser.
- While the annotation syntax is large, it just reflects the structure of VO-DML itself.
  - General purpose clients need to understand those concepts.
  - With those concepts understood, the (rather large) syntax is easily parseable.
  - Clients focused on a particular data model or use case may not care about all the details of VO-DML concepts.
- Libraries like rama will help for creating real instances of any model.
  - My C# parser was derived from a parser that handled the original syntax, so its design was very complex.
- Need to clarify desired behavior mapping between VOTable primitive types and VO-DML primitive types.
- This (rama) design makes it clear that code handling VO-DML can be kept separate from the rest of VOTable parsing.



Thank you!