GERMAN ASTROPHYSICAL
GAVO
VIRTUAL OBSERVATORY

Fig. 1

Asterics
Astronomy ESFRI & Research Infrastructure Cluster

Fig. 2

Fig. 3

1. Gaia DR2 Time Series at GAVO

(cf. Fig. 1)

Markus Demleitner
msdemlei@ari.uni-heidelberg.de

(cf. Fig. 2)

- What's the data?
- Time series as TAP-published arrays
- Cube-annotated time series through datalink
- Annotation details
- SSAP and Obscore

There's a less technical blog post on this:

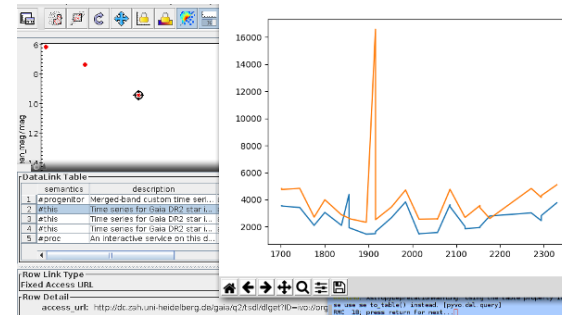https://blog.g-vo.org/tag/gaia

(cf. Fig. 3)

Fig. 4

Fig. 5

2. What's the data?

(cf. Fig. 4)

With data release 2 of Gaia, there are light curves for 0.5 million objects classified as variable in three bands (G, BP, and RP).

ESAC publishes these as VOTables, pointed to from mostly-NULL columns (`datalink_url` and `epoch_photometry_url`).

Grégory's Gaia-TAP service at ARI has a proper Datalink service block.

Although ESAC can produce per-band time series, their datalink links tables only point to mixed-band time series (where rows are, essentially band, time, flux). There is little machine-readable annotation on these time series.

Hence, I thought it might be a good idea to re-publish the time series data. Acknowledgement: Thanks to Grégory, who has handled the Gbin side of pulling the data.

3. TAP-Accessible Table

On http://dc.g-vo.org/tap, there's gaia.dr2epoch:

(cf. Fig. 5)

Arrays of NaN-filtered (epoch, flux, error) triples in G, RP, BP, plus source_id for joining with gaia_source.

Times are JD-2,455,197.5 here.

semantics	description	content_type	conter
#progenitor	Merged-band custom time seri...	application/x-votable+xml	
#this	G time series for Gaia DR2 677...	application/x-votable+xml	
#this	BP time series for Gaia DR2 67...	application/x-votable+xml	
#this	RP time series for Gaia DR2 67...	application/x-votable+xml	
#proc	An interactive service on this d...		

Fig. 6

4. Quick ADQL Example

Here's how to add RP and BP time series to Gaia DR2 objects where available:

```
SELECT b.*, bp_obs_time, bp_flux, rp_obs_time, rp_flux
FROM (SELECT
    main_id, source_id, g.ra, g.dec
    FROM
  gaia.dr2light as g
    JOIN TAP_UPLOAD.t1 AS tc
    ON (0.002>DISTANCE(tc.ra, tc.dec, g.ra, g.dec))
OFFSET 0) AS b
JOIN gaia.dr2epochflux
USING (source_id)
```

See the blog post cited above for an example how to use this.

5. Desideratum

For server-side bulk analysis for the light curves, it would be cool to have analysis capabilities in ADQL.

Who's in on designing an Array UDF library for ADQL? (You can already say things like SELECT rp_flux[1]-rp_flux[2]... in DaCHS, but that doesn't take you far here)

6. Datalink

ADQL query:

```
FROM gaia.dr2epochflux
JOIN gaia.dr2light
USING (source_id)
```

gives you a datalink block:

(cf. Fig. 6)

7. Time Series Annotation I

Sanitised cube/VO-DML annotation – this is exactly as shown in Shanghai:

```
<INSTANCE dmtype="ivoa:Measurement">
  <ATTRIBUTE dmrole="statError">
    <COLUMN ref="flux_error"/>
  </ATTRIBUTE>
  <ATTRIBUTE dmrole="value">
    <COLUMN ref="flux"/>
  </ATTRIBUTE>
</INSTANCE>

<INSTANCE dmtype="ndcube:Cube">
  <ATTRIBUTE dmrole="dependent_axes">
    <COLUMN ref="flux"/>
    <COLUMN ref="mag"/>
  </ATTRIBUTE>
  <ATTRIBUTE dmrole="independent_axes">
    <COLUMN ref="obs_time"/>
  </ATTRIBUTE>
</INSTANCE>
```

Over what's in the database, I'm also spitting out magnitudes in the VOTabled time series. Hence, there are two dependent axis. Only flux has errors, though.
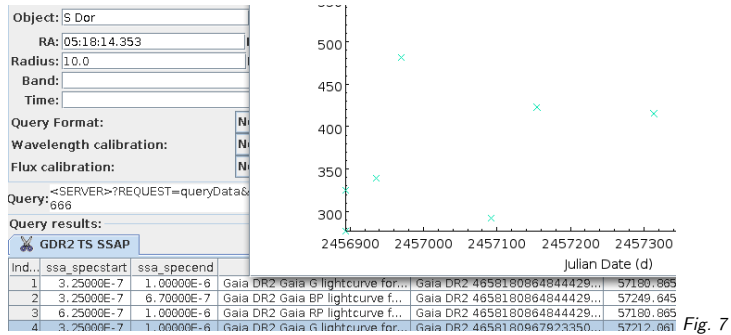
8. Time Series Annotation II

```
<INSTANCE dmtype="stc2:Coords">
  <ATTRIBUTE dmrole="time">
    <INSTANCE dmtype="stc2:TimeCoordinate">
      <ATTRIBUTE dmrole="frame">
        <INSTANCE dmtype="stc2:TimeFrame">
          <ATTRIBUTE dmrole="kind">
            <LITERAL dmtype="ivoa:string">JD</LITERAL>
          </ATTRIBUTE>
          <ATTRIBUTE dmrole="refPosition">
            <LITERAL dmtype="ivoa:string">BARYCENTER</LITERAL>
          </ATTRIBUTE>
          <ATTRIBUTE dmrole="timescale">
            <LITERAL dmtype="ivoa:string">TCB</LITERAL>
          </ATTRIBUTE>
        </INSTANCE>
      </ATTRIBUTE>
      <ATTRIBUTE dmrole="location">
        <COLUMN ref="obs_time"/>
      </ATTRIBUTE>
    </INSTANCE>
  </ATTRIBUTE>...
```

I'm not proposing LITERAL; I think we should have PARAMs for these and references to them. I *am* seriously proposing to only use attribute names in VO-DML serialisation.

The full time series deliver full, standard, JD.

For the full example, see, for instance:

http://dc.g-vo.org/gaia/q2/tsdl/dlget?ID=6779821003058453120&BANDPASS=RP

	Object:	S Dor	
	RA:	05:18:14.353	
	Radius:	10.0	
	Band:		
	Time:		
	Query Format:		N
	Wavelength calibration:		N
	Flux calibration:		N
	Query:	<SERVER>?REQUEST=queryData& 666	

Query results:

GDR2 TS SSAP

Ind..	ssa_specstart	ssa_specend			
1	3.25000E-7	1.00000E-6	Gaia DR2 Gaia G lightcurve for...	Gaia DR2 4658180864844429...	57180.865
2	3.25000E-7	6.70000E-7	Gaia DR2 Gaia BP lightcurve f...	Gaia DR2 4658180864844429...	57249.645
3	6.25000E-7	1.00000E-6	Gaia DR2 Gaia RP lightcurve f...	Gaia DR2 4658180864844429...	57180.865
4	3.25000E-7	1.00000E-6	Gaia DR2 Gaia G lightcurve for...	Gaia DR2 4658180967923350...	57212.061

Fig. 7

9. SSAP, Obscore

(cf. Fig. 7)

The time series can also be found, split-band, in an SSAP service and our obscore service. The figure shows that Splat can figure out that it's dealilng with time series.

Note that SSAP already has a TIME parameter that works nicely for what we have here. I've added custom time_min and time_max columns, though.

10. Homework

In principle it all works nicely. Except we're going a bit beyond where standardisation currently stands. To make all this covered by standards, we'd need:

- VOTable annotation syntax
- STC DM, Values/Error, independent/dependent axes
- Officially make 1D access protocol from SSAP?
- Advanced Array manipulation in ADQL?