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VOEvent Update: JSON and data models

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Abstract

We propose an extension of the VOEvent format, to **translate the packet from XML to JSON** – with no semantic change. We also propose to use the VOEvent data model system to define three data-model Groups: "**Light Curve**", "**Associated Sources**", and "**Followup Imaging**".

This straightforward update of VOEvent simplifies the syntax and provides simple, standard representation of common astronomical datasets.

Status of This Document

This is an IVOA Note expressing suggestions from and opinions of the authors. It is intended to share best practices, possible approaches, or other perspectives on interoperability with the Virtual Observatory. It should not be referenced or otherwise interpreted as a standard specification.

Contents

1 Introduction

The reason VOEvent exists is so the astronomical community should have a single interoperable celestial transient alert format and infrastructure. As time domain projects become more-and-more key to astronomy, the biggest risk is that each new, scientifically ambitious project will reinvent the wheel and that they will deploy systems that cannot interoperate. This is why we propose changes to VOEvent to keep its semantics and syntax on target for these new projects.

1.1 JSON Serialization

The future for transient studies in the optical wavelengths is dominated by the Large Synoptic Survey Telescope [LSST], that will look at the sky repeatedly, creating a bountiful harvest of transient event reports. The LSST project, as well as a precursor survey, ZTF, are exploring releasing the information portfolio in the AVRO format, closely related to the JSON format -- the target of the proposal below.

In Section 2, we propose a semantically equivalent version of the VOEvent.xml, but in JSON format. Some users are unhappy with the complexity of XML, the difficult distinction between attributes and text, for example, and general unreadability. The JSON format is popular because the structure is simple, and can be parsed simply in most languages (eg Python) without installing anything. We will build conversion utilities, JSON schema, and parsing code to accompany the standard.

While the JSON format proposed here is a straightforward semantic equivalent to the original XML version of VOEvent, it may be better to move directly to the format that will be used by the ZTF and LSST projects for disseminating transient alerts: the AVRO format [AVRO] can include binary data such as image cutouts that will be crucial to these projects. However JSON and AVRO are close in spirit and syntax. There are several possibilities:

- The Avro format might remain strictly internal to ZTF/LSST's full streams, with community brokers providing VOEvent 2.0 (or VOEvent-JSON) interfaces to science users;
- We could pursue standardization of the Avro-serialized formats and transport layers as they are implemented today, in parallel to VOEvent;
- We could evolve our Avro-based format to include some aspects of the VOEvent standard (such as citation) that are presently missing, and work towards an Avro-serialized version of VOEvent and associated recommendation for transport.

1.2 Data Models

VOEvents can carry a rich, customised, edible portfolio to an astronomer, with human and machine-readable data sufficient to decide if a rapid followup observation is warranted. VOEvents can also be used to respond with what was seen in the followup, citing the original VOEvent. The types of information to be put in these portfolios often fall into predictable patterns, and standardizing the way these are represented will make machine understanding much easier. We have selected three data models to represent common portfolio ingredients. This note introduces three data models:

- **Light Curve**: A timed set of flux/magnitude measurements of a source.
- **Associated Sources**: A set of catalogued sources associated with an event.
- **Followup Imaging**: A set of images taken in followup of an event.

Each of these data models is based on the UCD controlled vocabulary [UCD]. In a nutshell, if it supposed to be a light curve, and we see table columns for time and magnitude, then we know this is the core data. See section 3 for more details.

A Light Curve (Section 3.1) is a set of timed observations of flux/magnitude from a source, each of which may also contain error estimate, different filters, magnitude limits, non-observations (fainter than limit), and other attributes. We define this data model in terms of keywords, mandatory and optional, that have specific meanings (defined below). Many astronomers will choose "interesting" events based on the light curve, and producers of VOEvent would like to include this. Converting a table of observations to a VOEvent light curve is just a matter of labelling the relevant table columns with UCD [see ref UCD] values `time.epoch` and `phot.flux`.

In Section 3.2 we propose a data model for "Associated Sources": a collection of sources from catalogs that are near in the sky to the location of the event, and thus may be astrophysically connected. Examples: a supernova is the event, its galaxy an associated source; an event that is near to a known TeV-gamma source; alternate names for a given source. Each association is defined by source ID, catalog name and URL, as well as (angular) distance.

Each of the recent gravitational wave events has resulted in a furious follow-up effort, and a large number of GCN Circulars. However, these are written in natural language, and thus difficult for machines. The definition of the Followup Imaging data model of Section 3.3 is intended for reporting such observations in a machine-readable way, where each is defined by time and an (equatorial) rectangle on the sky, and limiting flux/magnitude can also be given.

The following updates to the VOEvent standard will pave the way for events and their followups to be expressed as a rich portfolio of semantic datasets, using an accepted (IVOA) standard. Sections 2 and 3 are independent. There can be a JSON format with no data models, and there can be data models in XML, without the JSON format.

2 Converting XML to JSON

To motivate the discussion, we use as example a community data model built with VOEvent [FRB] for the Fast Radio Bursts community, the result being the XML event shown in Appendix A.

Next we propose a JSON representation of the same information. A few points of explanation cover the keywords with yellow highlight below. In XML, a tag can be repeated, for example there is a **`Group`**, **`Param`** and **`Table`** for each such structure, but in a JSON dictionary keywords cannot be repeated; therefore for JSON we have **`Groups`**, **`Params`**, and **`Tables`** (plural), each being a list of structures. These are highlighted in yellow below.

In XML, there are no data types, so this must be made explicit with an attribute **`dataType`** in VOEvent. In converting to JSON, we have retained this, and also converted the type. Thus a quantity in XML would have `dataType="float"` and `value="1.234"`, but in the JSON version the quotes are removed, so it is a native float, and it appears as `"value":1.234`.

We have also simplified the many XML elements of the **`WhereWhen`** section. In the example below it is highlighted in yellow. The **`Position2D`** is simply a triple **`RA, Dec`**, **`Error2Radius`**, rather than a pair of names and a pair of values, and the error separate.

Code 1: VOEvent in JSON


```
{
  "version": "2.0",
  "ivorn": "ivo://au.csiro.atnf/parkes#FRB1405141714/56791.71885417",
  "role": "observation",

  "Who": {
    "Date": "2014-05-14T17:15:09",
    "AuthorIVORN": "ivo://au.csiro.atnf/contact",
    "Author": {
      "contactEmail": "ebpetroff@gmail.com",
      "contactName": "Emily Petroff"
    }
  },

  "Citations": [
    {
      "Description": "Updated source parameters",
      "cite": "supersedes",
      "ivorn": "ivo://au.csiro.atnf/parkes#1405141714/0000"
    }
  ],
```

```
"What": {
  "Groups": [
    {
      "name": "observatory parameters",
      "Params": [
        {
          "dataType": "float",
          "value": 7.5,
          "ucd": "instr.beam;pos.errorEllipse;phys.angSize.smajAxis",
          "name": "beam_semi-major_axis",
          "unit": "MM"
        },
        {
          "dataType": "float",
          "value": 7.5,
          "ucd": "instr.beam;pos.errorEllipse;phys.angSize.sminAxis",
          "name": "beam_semi-minor_axis",
          "unit": "MM"
        },
        {
          "dataType": "float",
          "value": 0.0,
          "ucd": "instr.beam;pos.errorEllipse;instr.offset",
          "name": "beam_rotation_angle",
          "unit": "Degrees"
        },
        {
          "dataType": "float",
          "value": 0.064,
          "ucd": "time.resolution",
          "name": "sampling_time",
          "unit": "ms"
        },
        {
          "dataType": "float",
          "value": 338.281,
          "ucd": "instr.bandwidth",
          "name": "bandwidth",
          "unit": "MHz"
        },
        {
          "dataType": "float",
          "value": 866.0,
          "ucd": "meta.number;em.freq;em.bin",
          "name": "nchan",
          "unit": "None"
        },
        {
          "dataType": "float",
          "value": 1352.0,
          "ucd": "em.freq;instr",
          "name": "centre_frequency",
          "unit": "MHz"
        },
        {
          "dataType": "int",
          "value": 2,
          "name": "npol",
          "unit": "None"
        },
        {
          "dataType": "int",
          "value": 2,
          "name": "bits_per_sample",
          "unit": "None"
        },
        {
          "dataType": "float",
          "value": 0.735,
          "name": "gain",
          "unit": "K/Jy"
        },
        {
          "dataType": "float",
          "value": 28.0,
          "ucd": "phot.antennaTemp",
          "name": "tsys",
          "unit": "K"
        },
        {
          "name": "backend",
          "value": "BPSR"
        },
        {
          "name": "beam",
          "value": "1"
        }
      ]
    },
    {
      "name": "event parameters",
      "Params": [
        {
          "dataType": "float",
          "value": 563.5,
          "ucd": "phys.dispMeasure;em.radio.750-1500MHz",
          "name": "dm",
          "unit": "pc/cm^3"
        },
```

```
          {
            "dataType": "float",
            "value": 1.0,
            "ucd": "stat.error;phys.dispMeasure",
            "name": "dm_error",
            "unit": "pc/cm^3"
          },
          {
            "dataType": "float",
            "value": 4.0,
            "ucd": "time.duration;src.var.pulse",
            "name": "width",
            "unit": "ms"
          },
          {
            "dataType": "float",
            "ucd": "stat.snr",
            "name": "snr",
            "value": 16.3
          },
          {
            "dataType": "float",
            "value": 0.37,
            "ucd": "phot.flux",
            "name": "flux",
            "unit": "Jy"
          },
          {
            "dataType": "float",
            "value": 50.841,
            "ucd": "pos.galactic.lon",
            "name": "gl",
            "unit": "Degrees"
          },
          {
            "dataType": "float",
            "value": -54.612,
            "ucd": "pos.galactic.lat",
            "name": "gb",
            "unit": "Degrees"
          }
        ]
      },
      {
        "name": "advanced parameters",
        "Params": [
          {
            "dataType": "float",
            "value": 34.9,
            "name": "MW_dm_limit",
            "unit": "pc/cm^3"
          },
          {
            "name": "galactic_electron_model",
            "value": "NE2001"
          },
          {
            "dataType": "float",
            "value": 0.44,
            "ucd": "src.redshift",
            "name": "redshift_inferred",
            "unit": "None"
          }
        ]
      }
    ]
  },

  "WhereWhen": {
    "ObservatoryPosition": {
      "ISOTime": "2014-05-14T17:14:11.060000",
      "Position2D": {
        "Error2Radius": 0.125,
        "Dec": -39.379,
        "RA": 19.114,
        "unit": "deg"
      },
      "AstroCoordSystem": "UTC-FK5-GEO"
    },
    "ObservatoryLocation": "PARKES"
  },
  "How": {
    "Description": "PID871"
  },
  "Why": {
    "importance": "1.0",
    "Name": "FRB140514"
    "Description": "Detection of a new FRB",
  }
}
```


Many people prefer the JSON format. It is easy to parse and manipulate the data, as illustrated in the following few lines of python code, followed by the results.

Code 2: JSON VOEvent

```
$ cat read_json_voevent.py
import sys
import json

# should provide file
e = json.loads(open(sys.argv[1]).read())

print "-------------------------------"
print "Event ", e["ivorn"]

for citation in  e["Citations"]:
    print "--> cites %s with role %s" % (citation["ivorn"], citation["cite"])

print "-------------------------------"
print e["Why"]["Description"]
print "Importance = ", e["Why"]["importance"]
print "Instrument: ", e["How"]["Description"]

print "-------------------------------"
ww = e["WhereWhen"]
print "AstroCoordSystem:", ww["AstroCoordSystem"]
print "ObservatoryLocation:", ww["ObservatoryLocation"]
wwp2d = ww["Position2D"]
print "    %25s = %s"    % ("Time",  ww["ISOTime"])
print "    %25s = %8.3f" % ("RA",    wwp2d["RA"])
print "    %25s = %8.3f" % ("Dec",   wwp2d["Dec"])
print "    %25s = %8.3f" % ("Error", wwp2d["Error2Radius"])

print "-------------------------------"
for group in e["What"]["Groups"]:
    print "--- ", group["name"], ":"
    for param in group["Params"]:
        if param.has_key("unit"):
            unit = param["unit"]
        else:
            unit = ""
        print "    %25s = %s %s" % (param["name"], param["value"], unit)
print "-------------------------------"
```

Code 3: Results

```
-------------------------------
Event  ivo://au.csiro.atnf/parkes#FRB1405141714/56791.71885417
--> cites ivo://au.csiro.atnf/parkes#1405141714/0000 with role supersedes
-------------------------------
Detection of a new FRB
Importance =  1.0
Instrument:  PID871
-------------------------------
AstroCoordSystem: UTC-FK5-GEO
ObservatoryLocation: PARKES
                         Time = 2014-05-14T17:14:11.060000
                           RA =   19.114
                          Dec =  -39.379
                        Error =    0.125
-------------------------------
---  observatory parameters :
         beam_semi-major_axis = 7.5 MM
         beam_semi-minor_axis = 7.5 MM
          beam_rotation_angle = 0.0 Degrees
                sampling_time = 0.064 ms
                    bandwidth = 338.281 MHz
             centre_frequency = 1352.0 MHz
                         npol = 2
              bits_per_sample = 2
                         gain = 0.735 K/Jy
                         tsys = 28.0 K
                      backend = BPSR
                         beam = 1
---  event parameters :
                           dm = 563.5 pc/cm^3
                     dm_error = 1.0 pc/cm^3
                        width = 4.0 ms
                          snr = 16.3
                         flux = 0.37 Jy
                           gl = 50.841 Degrees
                           gb = -54.612 Degrees
---  advanced parameters :
      galactic_electron_model = NE2001
             redshift_inferred = 0.44 pc/cm^3
-------------------------------
```

2.1 Tables

One of the features of the VOEvent specification is the ability to embed a **`Table`**. It can have a name, **`Description`**, **`Params`**, but what makes it a table are the **`Fields`** and the **`Data`** sections. The latter is a list of lists of primitive quantities (float, int, string), and the former a list of "column headings", defining the name, unit, ucd, etc for the corresponding parts of the **`Data`** section. If there are N Fields, then the **`Data`** section should be a list of “rows”, where each row is a list of length N. The following is an example of a **What** section, containing a **Table**, in the proposed JSON version of VOEvent:

Code 4: A Table in the JSON VOEvent


```
{
  "What": {
    "Tables": [{
      "name": "Table IV",
      "Params": [{
        "name": "telescope",
        "value": "PARKES"
      }],
      "Description": "Individual Moduli and Distances for NGC 0931 from NED",
      "Fields": [{
          "name": "(m-M)",
          "unit": "mag",
          "ucd": "phot.mag.distMod",
          "datatype": "float"
        },
        {
          "name": "err(m-M)",
          "unit": "mag",
          "ucd": "phot.mag.distMod;stat.err",
          "datatype": "float"
        },
        {
          "name": "D",
          "unit": "Mpc",
          "ucd": "pos.distance"
          "datatype": "float"
        },
        {
          "name": "REFCODE",
          "ucd": "meta.bib.bibcode"
        }
      ],
      "Data": [
        [33.16, 0.38, 51.3, "1997ApJS..109..333W"],
        [33.32, 0.38, 46.1, "1997ApJS..109..333W"],
        [33.51, 0.48, 50.4, "2009ApJS..182..474S"],
        [33.55, 0.38, 51.3, "1997ApJS..109..333W"],
        [33.71, 0.43, 55.2, "2009ApJS..182..474S"],
        [34.01, 0.80, 63.3, "1997ApJS..109..333W"]
      ]
    }]
  }
}
```


3 Data Models

The VOEvent specification contains a mechanism for specifying data models. In the **What** section, there can be **Tables** containing **Fields**, and each of these can have tags – **type** for the **Table** and **ucd** for the **Fields** -- to indicate a specific data model. In the following we define two such data models, one for “Light Curve” and one for “Associated Sources”.

We use the semantics of the Unified Content Descriptors (see ref [UCD]). To be a light curve, a table must have a time column (ucd=pos.time), and a flux column (ucd=phot.flux). To be an associated source, there must be a an identifier of the source (ucd=meta.id.parent), and a catalog from which it comes (ucd=meta.table), and it may also have angular separation, RA, Dec etc. Thus the UCD signature of the table corresponds to the meaning of the table.

The VOEvent format allows the use of “UType” as an alternative to UCDs for the data models. We would welcome input from one who has more expertise in IVOA data models, and could define these data models in terms of UTypes, to align properly with other, already-defined, data models.

3.1 Light Curve Data Model

A VOEvent light curve is a VOEvent table, that is distinguished by a specific “type” attribute. In this case we have chosen this string to be a URL that points to this section of this paper, which defines the light curve model:

"type": http://ivoa.net/documents/Notes/VOEventJSON#LightCurve

Once the consumer has recognized the table as a light curve, they have a right to expect Fields (columns) of the Table with the following UCDs, which MUST be present:

- **time.epoch**: the time of a flux measurement
- **phot.flux**: the measured flux

If Fields or Params are present with the following UCDs, they should be interpreted with the following meanings:

- **phot.flux;stat.error**: the error in the flux measurement
- **phot.flux;stat.min**: the limiting magnitude of the measurement
- **instr.filter**: the filter used for the measurement

An important semantic here is handling of non-detections, also known as upper limits. If there is a magnitude limit (phot.flux;stat.min), then any value of the measured flux that is less than that limit will be taken to be a *non-detection*. In other words magnitude=99 means a non-detection, not the measurement of an incredibly faint source.

Null measurements are different from non-detections, it means that no information is available about the source brightness at that time. In this case, it should not be included in the VOEvent at all.

If there are multiple Fields or Params with the same UCD, then one of them must have the postfix "`meta.main`" to show it is the most relevant one. In the example below, the time in HJD is considered "`meta.main`", backed up by the time in UTC.

In the example below is a light curve that has time in heliocentric Julian Day, time in UT, the FWHM of the observation, the limiting magnitude of the observation, the observed magnitude and error of that magnitude. The yellow highlights indicate the type and controlled UCD vocabulary as defined above.

Code 5: A Light Curve in the JSON VOEvent

```
{
 "What": {
   "Tables": [{
     "name": "lightcurve HD 50948",
     "type": "http://ivoa.net/documents/Notes/VOEventJSON#Lightcurve",
     "Description": "Light curve for the star HD 50948 in R band",
     "Params: [{
         "name":"Filter used for lightcurve",
         "ucd": "instr.filter",
         "value": "R"
     }]
     "Fields": [{
         "name": "time",
         "ucd": "time.epoch;meta.main",
         "unit": "HJD",
         "dataType": "float"
       },
       {
         "name": "UT Date",
         "ucd": "time.epoch",
         "unit": "ISO8601"
       },
       {
         "name": "FWHM",
         "unit": "arcsec",
         "ucd": "phys.angSize",
         "dataType": "float"

       },
       {
         "name": "limiting magnitude",
         "ucd": "phot.flux;stat.min",
         "unit": "mag",
         "dataType": "float"

       },
       {
         "name": "observed magnitude",
         "ucd": "phot.flux",
         "unit": "mag",
         "dataType": "float"

       },
       {
         "name": "magnitude error",
         "ucd": "phot.flux;stat.error",
         "unit": "mag",
         "dataType": "float"
       }

     ],
     "Data": [
```

```
        [2456227.024, "2012-10-26.5202516", 2.27, 16.644, 14.758, 0.039],
        [2456227.026, "2012-10-26.5221553", 2.27, 16.688, 14.81, 0.039],
        [2456228.985, "2012-10-28.4806849", 2.34, 16.269, 14.586, 0.047],
        [2456228.987, "2012-10-28.4824892", 2.35, 16.541, 14.62, 0.037],
        [2456230.983, "2012-10-30.4791961", 2.33, 16.165, 14.675, 0.056],
        [2456230.985, "2012-10-30.4809271", 2.32, 16.219, 14.712, 0.055],
        [2456239.94,  "2012-11-08.4352982", 2.01, 17.156, 14.994, 0.030],
        [2456239.942, "2012-11-08.4374127", 2.01, 17.152, 15.034, 0.031],
        [2456242.988, "2012-11-11.4835951", 2.09, 17.056, 14.893, 0.030],
        [2456242.991, "2012-11-11.4857293", 2.09, 17.248, 14.88, 0.025],
        [2456251.94,  "2012-11-20.4347585", 2.12, 15.926, 14.8, 0.078],
        [2456251.942, "2012-11-20.4365331", 2.13, 16.258, 14.794, 0.05741]
      ]
    }]
  }
}
```

3.2 Associated Sources Data Model

The Associated Sources data model is to report on sources nearby in the sky to an event, chosen from some catalog. The presence of this data model is indicated by the "type" of the `Table` object, as follows:

"type": http://ivoa.net/documents/Notes/VOEventJSON#AssociatedSources

The catalogs from which these sources are derived might be standard ones like 2MASS or the Messier catalog, or arbitrary, unpublished catalogs of sources. In either case, it is expected that each object have an identifier, and the catalog be identified by some text, and there may also be a reference or link of some kind. The following UCDs **must** occur in the data model:

- **meta.id.parent**: and identifier of the parent source
- **meta.table**: the catalog from which the source comes

Then any of the following UCDs may be used, and if they are, they must have the meanings written here:

- **meta.ref.uri**: Universal resource identifier, a reference for the catalog, generally a URL
- **phys.angSize**: Angular distance from the point
- **pos.eq.ra**: Right ascension of the associated source
- **pos.eq.dec**: Declination of the associated source
- **pos;stat.error**; Error of the positional information
- **stat.probability**; Strength of the association between the subject of this VOEvent and the given source

Instead of the RA and Dec of the associated source, other systems may be used, for example galactic (**pos.galactic.lat** and **pos.galactic.lon**)

Here is a simple example of a set of associated sources taken from the Simbad system, those within 10 arcmin of the point RA=30, Dec=30:

Code 6: Associated Sources in the JSON VOEvent

```
{
  "What": {
    "Tables": [{
      "Description": "Simbad objects near RA=30d, Dec=+30d",
      "type": "http://ivoa.net/documents/Notes/VOEventJSON#AssociatedSources",
      "Fields": [{
          "name": "distance",
          "unit": "arcsec",
          "ucd": "phys.angSize",
          "dataType="float"
        },
        {
          "name": "identifier",
          "ucd": "meta.id.parent"
        },
        {
          "name": "catalog",
          "ucd": "meta.table"
        },
        {
          "name": "RA",
          "ucd": "pos.eq.ra",
          "dataType="float"
        },
        {
          "name": "Dec",
```

```
            "ucd": "pos.eq.dec",
            "dataType="float"
          },
          {
            "name": "Positional error",
            "ucd": "pos;stat.error",
            "dataType="float"

          },
          {
            "name": "Strength of association",
            "ucd": "stat.probability",
            "dataType="float"
          }

        ],
        "Data": [
          [63.90, "2MASX J02000350+3000447" , "2MASX", 30.014621, 30.012442],
          [188.21, "TYC 1763-15-1"          , "TYC"  , 29.987428, 29.948865],
          [261.50, "TYC 1763-129-1"         , "TYC"  , 30.078452, 29.974323],
          [369.39, "TYC 1763-249-1"         , "TYC"  , 30.069709, 29.917050],
          [381.93, "2MASX J02002937+2959443", "2MASX", 30.122400, 29.995653],
          [383.40, "TYC 1763-289-1"         , "TYC"  , 30.004912, 29.893585],
          [415.20, "TYC 2308-2113-1"        , "TYC"  , 29.870192, 30.025831],
          [529.83, "2MASX J02002962+2953560", "2MASX", 30.123442, 29.898903],
          [596.18, "BD+29 343"              , "BD"   , 29.812730, 29.966627],
          [596.65, "HD 12232"               , "HD"   , 30.174441, 29.931953]
        ],
    }
}
```

3.3 Followup Imaging Data Model

The Followup Imaging data model is to report on observations made by a telescope in response to a rapid alert. It carries the idea of rectangles on the sky (that contain the imaged area), and the limiting flux that the telescope could detect. The presence of this data model is indicated by the "type" of the `Table` object, as follows:

"type": http://ivoa.net/documents/Notes/VOEventJSON#FollowupImaging

While the rectangles described in this model are aligned with the equatorial (RA, Dec) axes, the imaged areas need not be aligned in this way, or even rectangular. The rectangle on the sky should be the *minimum enclosing rectangle* of the observational followup image.

The following UCDs **must** occur in the data model.

- **pos.eq.ra** and **pos.eq.dec**: the center of the image rectangle
- **pos.eq.ra;phys.angSize** and **pos.eq.dec;phys.angSize**: the width of the image rectangle in the RA and Dec directions
- **time.epoch**: the time at which the image data was taken

Then any of the following UCDs may be used, and if they are, they must have the meanings written here:

- **phot.flux;stat.min**: The limiting flux that the telescope reached at the time of taking data
- **meta.note**: the shape of the area imaged, can be "rectangular", "ellipse", or "irregular".

Some of these quantities can appear as `Params` rather than `Fields`, if they are the same for each of the rows of the `Table`. In the example below, the image size is the same for each observation (3 degrees x 3 degrees), and the limiting magnitude is the same for each, therefore these quantities appear as **`Params`.**

Code 7: Followup Imaging in the JSON VOEvent

```
{
  "What": {
    "Tables": [{
      "name": "Followup to GW190919",
      "type": "http://ivoa.net/documents/Notes/VOEventJSON#FollowupImaging",
      "Description": "Followups to GW190919 by the Yor Telescope",
      "Params": [{
          "name": "RA diameter",
          "ucd": "pos.eq.ra;phys.angSize",
          "unit": "deg",
          "dataType": "float",
          "value": 3.0
        },
        {
          "name": "Dec diameter",
```

```
          "ucd": "pos.eq.dec;phys.angSize",
          "unit": "deg",
          “dataType": “float”,
          "value": 3.0
        },
        {
          "name": "limiting magnitude",
          "ucd": "phot.flux;stat.min",
          "unit": "mag",
          "dataType": "float",
          "value": 18.3

        },
        {
          "name": "image shape",
          "ucd": "meta.note",
          "value": “rectangular”
        }

      ],
      "Fields": [{
          "name": "time",
          "ucd": "time.epoch",
          "unit": "GPS",
          "dataType": "float"
        },
        {
          "name": "RA center",
          "ucd": "pos.eq.ra",
          "unit": "deg",
          "dataType": "float"
        },
        {
          "name": "Dec center",
          "ucd": "pos.eq.dec",
          "unit": "deg",
          "dataType": "float"
        }
      ],
      "Data": [
        [1252892803, 19.644, 31.0203, 32.8748],
        [1252893988, 19.644, 29.7468, 32.8647],
        [1252895484, 19.644, 31.1232, 29.8123],
        [1252896794, 19.644, 29.5674, 29.9873]
      ]
    }]
  }
}
```


4 Conclusion

The translation of XML to JSON proposed in Section 2 is not difficult, and automated conversion tools already exist and have been used for all the examples in this note. Many potential users of VOEvent have been put off by the unfamiliar XML format, and may be more enthusiastic to use a JSON version. The next step after JSON would be the more sophisticated AVRO format, allowing direct inclusion of binary image cutouts. It may be more effective to go directly to AVRO, although the simplicity and ubiquity of JSON remains attractive.

The three data models proposed are simple and pragmatic, so that users can quickly build a VOEvent to contain common semantics. However, it should be emphasised that any number of other table columns maybe used in concert to express much more sophisticated models of light curves, associated sources, and followup imaging.

Appendix

Code 8: FRB community VOEvent in XML


```
<?xml version='1.0' encoding='UTF-8'?>
<voe:VOEvent xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns:voe="http://www.ivoa.net/xml/VOEvent/v2.0"
xsi:schemaLocation="http://www.ivoa.net/xml/VOEvent/v2.0 http://www.ivoa.net/xml/VOEvent/VOEvent-v2.0.xsd"
version="2.0" role="observation" ivorn="ivo://au.csiro.atnf/parkes#FRB1405141714/56791.71885417">
    <Who>
         <AuthorIVORN>ivo://au.csiro.atnf/contact</AuthorIVORN>
         <Date>2014-05-14T17:15:09</Date>
         <Author><contactEmail>ebpetroff@gmail.com</contactEmail><contactName>Emily Petroff</contactName></Author>
    </Who>
        <What>
        <Group name="observatory parameters">
            <Param dataType="float" name="beam_semi-major_axis" ucd="instr.beam;pos.errorEllipse;phys.angSize.smajAxis"
unit="MM" value="7.5"/>
            <Param dataType="float" name="beam_semi-minor_axis" ucd="instr.beam;pos.errorEllipse;phys.angSize.sminAxis"
unit="MM" value="7.5"/>
            <Param dataType="float" name="beam_rotation_angle" ucd="instr.beam;pos.errorEllipse;instr.offset"
unit="Degrees" value="0.0"/>
             <Param dataType="float" name="sampling_time" ucd="time.resolution" unit="ms" value="0.064"/>
             <Param dataType="float" name="bandwidth" ucd="instr.bandwidth" unit="MHz" value="338.281"/>
```

```
            <Param dataType="float" name="nchan" ucd="meta.number;em.freq;em.bin" unit="None" value="866"/>
             <Param dataType="float" name="centre_frequency" ucd="em.freq;instr" unit="MHz" value="1352"/>
             <Param dataType="int" name="npol" unit="None" value="2"/>
             <Param dataType="int" name="bits_per_sample" unit="None" value="2"/>
             <Param dataType="float" name="gain" unit="K/Jy" value="0.735"/>
             <Param dataType="float" name="tsys" ucd="phot.antennaTemp" unit="K" value="28.0"/>
             <Param name="backend" value="BPSR"/>
             <Param name="beam" value="1"/><Description>Detection beam number if backend is a multi beam
receiver</Description>
        </Group>
        <Group name="event parameters">
             <Param dataType="float" name="dm" ucd="phys.dispMeasure;em.radio.750-1500MHz" unit="pc/cm^3"
value="563.5"/>
             <Param dataType="float" name="dm_error" ucd="stat.error;phys.dispMeasure" unit="pc/cm^3" value="1.0"/>
             <Param dataType="float" name="width" ucd="time.duration;src.var.pulse" unit="ms" value="4.0"/>
             <Param dataType="float" name="snr" ucd="stat.snr" value="16.3"/>
             <Param dataType="float" name="flux" ucd="phot.flux" unit="Jy" value="0.37"/>
             <Param dataType="float" name="gl" ucd="pos.galactic.lon" unit="Degrees" value="50.841"/>
             <Param dataType="float" name="gb" ucd="pos.galactic.lat" unit="Degrees" value="-54.612"/>
        </Group>
        <Group name="advanced parameters">
             <Param dataType="float" name="MW_dm_limit" unit="pc/cm^3" value="34.9"/>
            <Param name="galactic_electron_model" value="NE2001"/>
             <Param dataType="float" name="redshift_inferred" ucd="src.redshift" unit="None"
value="0.44"><Description>Inferred redshift from NE2001 DM excess.</Description></Param>
         </Group>
    </What>
    <WhereWhen>
         <ObsDataLocation>
            <ObservatoryLocation id="PARKES">
            </ObservatoryLocation>
            <ObservationLocation>
                 <AstroCoordSystem id="UTC-FK5-GEO"/><AstroCoords coord_system_id="UTC-FK5-GEO">
                 <Time unit="s"><TimeInstant>
                     <ISOTime>2014-05-14T17:14:11.060000</ISOTime></TimeInstant></Time>
                 <Position2D unit="deg"><Name1>RA</Name1><Name2>Dec</Name2>
                     <Value2><C1>19.114</C1><C2>-39.379</C2></Value2>
                     <Error2Radius>0.125</Error2Radius></Position2D>
                 </AstroCoords>
            </ObservationLocation>
        </ObsDataLocation>
    </WhereWhen>

    <How>
        <Description>PID871</Description>
    </How>

    <Why importance="1.0">
           <Concept></Concept><Description>Detection of a new FRB</Description>
       <Name>FRB140514</Name>
    </Why>

    <Citations>
        <EventIVORN cite=" supersedes">ivo://au.csiro.atnf/parkes#1405141714/0000</EventIVORN>
        <Description>Updated source parameters</Description>
    </Citations>

</voe:VOEvent>
```


References

[VOEvent]
Sky Event Reporting Metadata Version 2.0 http://www.ivoa.net/documents/VOEvent/

[LSST] Large Synoptic Survey Telescope https://www.lsst.org/

[ZTF] Zwicky Transient Facility https://www.ptf.caltech.edu/ztf

[AVRO] Apache Avro, a data serialization system https://avro.apache.org/

[FRB]
E. Petroff, Fast radio bursts: recent discoveries and future prospects https://arxiv.org/abs/1709.02189

L. Houben & E. Petroff, VOEvent standard for FRBs http://aspen17.phys.wvu.edu/Houben.pdf

[UCD]
The Unified Content Descriptors Controlled Vocabulary http://www.ivoa.net/documents/latest/UCDlist.html