Sky Event Reporting Metadata (*VOEvent*) Version 0.90

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Abstract

VOEvent defines the content and meaning of a standard information packet for representing, transmitting, publishing and archiving the discovery of a transient celestial event, with the common implication that timely followup is being requested. The objectives are to motivate the observation of targets-of-opportunity, to drive robotic telescopes, to trigger archive searches, and to alert the community for whatever purpose. VOEvent is focused on the reporting of photon events, but events mediated by disparate phenomena such as neutrinos, gravitational waves, and solar or atmospheric particle bursts may also be reported.

Structured data is used, rather than natural language, so that automated systems can effectively interpret VOEvent packets. Each packet may contain one or more of the "who, what, where, when & how" of a detected event, but in addition, may contain a hypothesis regarding the nature of the underlying physical cause of the event. Citations to previous VOEvents may be used to place each event in its correct context. Proper curation is encouraged throughout each event's life cycle, with options such as discovery, follow-up and retraction.

VOEvent packets gain persistent identifiers and are typically stored persistently in databases and registries. VOEvent packets may therefore reference other packets in various ways. Subscribers receive immediate notification of events, based on previously defined criteria. This standard does not define a transport layer or the design of clients, registries or aggregators. The intended usage of a VOEvent

packet does, however, require packets to be small and be processed quickly, allowing humans or machines to get very fast notification. The standard does not cover policy issues such as who can publish, who can build a registry of events, who can subscribe to a particular registry, nor the intellectual property issues.

1. Introduction

Throughout human history, unexpected events in the sky have been interpreted as portents and revelations. Modern curiosity seeks to use such transient events to probe the fundamental nature of the universe. In the next decade the scientific study of such events will be greatly extended by digital technology, with many new survey projects making wide-area systematic searches for time-varying astronomical events, and with a large number of robotic facilities standing ready to respond. These events may reflect purely local solar system phenomena such as comets, solar flares, asteroids and Kuiper Belt Objects, or those more distant such as gravitational microlensing, supernovae and Gamma-Ray Bursts (GRBs). Most exciting of all may be new and unknown types of event, heralding new horizons for astrophysics. Searches for astrophysical events are taking place at all electromagnetic wavelengths from gamma-rays to radio. There are also quests for more exotic events conveyed by such means as neutrinos, gravitational waves or high-energy cosmic rays.

For many types of events, astrophysical knowledge is gained through fast, comprehensive followup observation — perhaps the immediate acquisition of the spectrum of an optical counterpart, for example — and in general, by observations made with instruments in different wavelength regimes or at different times. To satisfy these needs, several projects are commissioning robotic telescopes to respond to digital alerts by pointing the telescope and triggering observations in near real-time and without human intervention. Automated systems may also query archives and initiate pipelines in response to such alerts.

Many projects have been conceived — with some now in operation — that will discover such time-critical celestial events. These include a large number of robotic survey and monitoring telescopes with apertures from tens of centimeters to tens of meters, large-field survey projects like Palomar-QUEST [7], Pan-STARRS [8] and LSST [6], satellites like Swift [9], and more singular experiments like LIGO [5]. The community has demonstrated that robotic telescopes [10] can quickly follow-up events. In the past, human-centric event alert systems have been very successful, including the Central Bureau for Astronomical Telegrams (CBAT) [2] and the Astronomer's Telegram (ATEL) [1], but these systems use predominantly natural-language text to describe each event, and send every accepted event to all subscribers. The GRB Coordinates Network (GCN) [3] reports one of the most exciting event streams of current times, and its events are transmitted very successfully for followup within seconds or minutes. With VOEvent, we would like to leverage the success of GCN by making it interoperable with other producers of events, and by generalizing its transport mechanisms.

A much larger rate of events can be expected as new facilities are commissioned or more fully automated. These rates represent events that must be handled by machines, not humans. Subscribing agents must be able to automatically filter out a tractable number of events without missing any that may be key to achieving their goals. In general, the number of pending events from a large-scale survey telescope (such as LSST) that are above the horizon at a given observatory during a given observing session may be orders of magnitude larger than a human can sift through productively. Selection criteria will need to be quite precise to usefully throttle the incoming event stream(s) — say — *"give me all events in which a point source R-band magnitude increase of at least -2.0 was seen to occur in less than four hours, that are located within specified molecular column density contours of a prioritized list of galactic star forming regions"*. In practice the result of complex queries such as these will be transmitted through intermediary "aggregators" — which will subscribe to VOEvent-producing systems and provide filter services to client groups ("listeners") via specialized VOEvents. Filtering will often be based on coincidence between multiple events. A gravitational wave detector may produce a large number of candidate events, but the interesting ones may be only those that come from multiple observatories.

Handling the anticipated event rates quickly and accurately will require alert packets to be issued in a structured data format, not natural language. Such a structured discovery alert — and any follow-up packets — will be referred to as a VOEvent. VOEvent will rely on XML schemata [18] to provide the appropriate structured syntax and semantics. These schemata may be specific to VOEvent or may reference external libraries such as the IVOA's Space-Time Coordinate (STC) metadata specification

[14] or the Remote Telescope Markup Language (RTML) [11].

VOEvent is a pragmatic effort that crosses the boundary between the Virtual Observatory and the larger astronomical community. The results of "real" astronomical observations using real telescopes must be expressed using the IVOA VOEvent standard, be recorded and transmitted via registries and aggregators within and outside the VO, and then be captured and filtered by subscribing VO clients. Each event that survives rigorous filtering can then be passed to other real (or possibly virtual) telescopes, for instance via RTML, to acquire real follow-up observations that will confirm (or deny) the original hypothesis as to the classification of the object(s) or processes that generated that particular VOEvent in the first place. This must happen quickly (often within seconds of the original VOEvent) and must minimize unnecessary expenditures of either real or virtual resources.

VOEvent is a mechanism for broadcasting discoveries that others may wish to followup, and this purpose defines its scope. An astronomical discovery that cannot benefit from immediate followup is not a good candidate for expression as a VOEvent.

Following the Abstract and Introduction, this document contains a discussion of appropriate VOEvent usage in §2. Section 3 is the heart of the document, conveying the semantics of a VOEvent packet. Explicit examples of VOEvent packets are in §4, and linked references in §5. The Appendix supplies context with a discussion of prior astronomical event systems.

2. Usage

This document defines the semantics of an alert packet known as VOEvent. In this document, the word *packet* will refer to a single, syntactically complete, VOEvent alert or message, however transmitted or stored. The transmission of such a packet announces that an astronomical "event" has occurred, or provides information contingent on a previous VOEvent. The packet may include information regarding the "who, what, where, when & how" of the event, and may express one or more hypotheses regarding the physical cause of the observed event and the likelihood of each of these hypotheses.

2.1 VO Identifiers

VOEvent benefits from the IVOA identifier syntax developed for the VO registry. These identifiers are required to begin with *"ivo://"*, and are meant to stand in for a particular metadata packet, obtainable from a VO registry. A *registered* VOEvent packet is one that has a valid identifier — meaning that a registry exists that can resolve that identifier to the full VOEvent packet. The identifiers thus provide a citation mechanism — a way to express that one VOEvent packet is a *follow-up* in some fashion of a previous packet.

Another way to use VO identifiers is for efficiency. One section of the VOEvent schema is about curation (who is responsible for this candidate discovery), and that section may be replaced by a VO identifier which points to the relevant organization. If a group creates similar VOEvent packets regularly, it would be preferable to use the VO identifier in each packet rather than sending the whole list of people and contacts each time.

For these reasons, VOEvent packets will often contain VO identifiers, as defined and discussed in ref. [12]. These take the general form *"ivo://**authorityID/resourceKey**"*, and are references to metadata packets that may be found at a VO registry or VOEvent database.

The lookup procedure is similar to looking up a URL on the world wide web: each registry controls a number of ***authorityIDs***. These are like domain names on the net: each is resolved to exactly one endpoint machine through a system of distributed knowledge. Once that machine is discovered, it should be able to resolve the secondary part of the identifier, the ***resourceKey***. Indeed, the machine that holds an ***authorityID*** has made a promise to continue to resolve all the ***resourceKeys*** that it has issued. The corresponding organization has the responsibility for ensuring that VOEvents once issued remain available indefinitely via their VO identifiers.

2.2 Publishing VOEvents

It is expected that VOEvent packets will be used as the basis of an information infrastructure of databases, or registries, that hold VOEvent packets, keyed by their identifiers. These databases may harvest packets from each other, so that a packet may be held in more than one database. In addition to the harvesting protocol, there would be three ways for clients to interact with the database servers:

- **Publishing**: a client creates a VOEvent packet without an IVO identifier, communicates with some database server to add the packet to the holdings and get the persistent identifier.
- **Subscription**: a client can create a query and lodge it within a VOEvent-compatible database; whenever a packet comes in that matches the query, the client is immediately informed about the new packet.
- **Search**: a client can send a query to a VOEvent database server, and obtain all event packets which match it.

Transport mechanisms could include email and cellphone, as well as one-way web services. The IVOA Events Working Group is responsible for suggesting best practices and ensuring interoperability. The intent is to work with the IVOA to define a message protocol by which a VOEvent packet may obtain a valid IVOA identifier from a database of such packets. Broadly speaking, the creator of a packet (a VOEvent publisher) will submit the packet with an empty identifier to a Publisher, who will check syntax and respond with the same packet, but with the identifier filled in.

The subscription mechanism is expected to be the chief way in which users will be informed of new events. A subscription to an event service is a filter on the stream of events that an event registry processes: whenever certain criteria are met for an incoming event, the subscriber is notified by a transport mechanism that the subscriber has chosen. The filter may involve the curation part of the event (*e.g.*, *"all events published by the Swift spacecraft"*), the location (*"anything in M31"*), or they may involve the detailed metadata of the event itself (*"whenever the cosmic ray energy is greater than 3 TeV"*).

The discovery of a new celestial phenomenon may be Nobel-prize material, and it is hoped that a VOEvent packet will be the chosen medium for its announcement. The astronomical community generally prefers open systems — VOEvent packets do not convey intellectual property (IP) restrictions on the data they contain. Organizations can work within a closed system of clients and servers if privacy is required. This solution is simpler and more effective than demanding that all servers understand a schema for IP restriction.

3. VOEvent Semantics

A VOEvent packet provides a general purpose mechanism for representing transient astronomical events. However, not all VO data are suitable for expression using VOEvent. The VOEvent schema is as simple as practical to allow the minimal representation of scientifically meaningful, time critical, events. VOEvent also borrows other standard VO and astronomical schema, specifically STC for space-time coordinates and RTML to represent instrument configurations. The usual IVOA standards such as registries and UCD identifiers are used. VOEvent has a strong interest in the development of complete and robust astronomical ontologies, but must rely on pragmatic and immediately useful prototypes of planned facilities.

By definition, a VOEvent packet contains a single XML **<VOEvent>** element. Multiple **<VOEvent>** elements may be jointly contained within a larger XML document, but these should be handled as separate alert packets. A **<VOEvent>** element may contain zero or more of each of the following sub-elements:

<Citations>
<Curation> — *i.e., "Who?"*
<What>
<WhereWhen>
<How>
<Hypothesis>
<Description>

Alternately, a **<VOEvent>** element may be completely empty except for a single **<Reference>** element as described in §3.9 below.

Only those elements required to convey the event being described need be present; the ordering of elements is immaterial to interpretation, but may be important for efficient processing in demanding applications. Any number of sub-elements of each type may be included in a single VOEvent — however, the intent of VOEvent is to describe a single astronomical transient event per packet. Multiple events should be expressed using multiple packets. XML structures other than those listed in this document are not recommended for use within a **<VOEvent>** element. Section 4 contains examples of complete VOEvent packets.

3.1 **<VOEvent>** — identifiers, roles and versions

The **<VOEvent>** element expresses the discovery of a sky transient event, located in a region of space & time, observed by an instrument, and published by a person or institution who may have developed a hypothesis about the underlying classification of the event.

A **<VOEvent>** element has three attributes:

> 3.1.1 ***id*** — Each VOEvent packet is required to have one-and-only-one identifier, expressed with the ***id*** attribute. VOEvent identifiers are URIs [12]. As the issuance of duplicate identifiers would diminish the trust placed in systems exchanging VOEvents, it is anticipated that a number of VOEvent registries will be founded to issue unique IDs from a variety of useful and appropriate namespaces.
>
> 3.1.2 ***role*** — The optional ***role*** attribute accepts two possible enumerated values, *"test"* or *"actual"*. The value *"actual"* is the default if the **role** is missing; this means that the packet describes an observation of the actual universe. The value *"test"*, means that the packet does not describe actual astronomical events, but rather is part of a testing procedure of some kind.
>
> **It is the responsibility of all who receive VOEvent packets to pay attention to the *role*, and to be quite sure of the difference between an actual event and a test of the system.**
>
> 3.1.3 ***version*** — The ***version*** attribute is required to be present and to equal the value taken from the title of this document, for all VOEvent packets governed by this version of the standard. There is no default value.

For example, a **<VOEvent>** packet resulting from Tycho Brahe's discovery of a "Stella Nova" in Cassiopeia on 11 November 1572 [22] might start:

> *<VOEvent id="ivo://uraniborg.hven/1572-11-11/0001" role="actual" version="0.90" xmlns:... >*

The ***xmlns*** attribute refers to one-or-more standard XML namespace declarations that may optionally help define the contents of a packet.

3.2 **<Citations>**

A VOEvent packet without a **<Citations>** element can be assumed to be asserting information about a new celestial discovery. Citations reference previous events to do one of three things:

- follow-up on an event alert with more observations, or
- supersede a prior event with better information, or
- issue a complete retraction of a previous event.

In addition, citations allow merging multiple events into a single related thread, or contrarily, allow separating a single event into multiple threads.

A **<Citations>** element contains one or more **<EventID>** elements. The standard does not attempt to enforce references to be logically consistent; this is the responsibility of publishers and subscribers.

3.2.1 <EventID> — references and cites

An **<EventID>** element contains the ID of a previously published VOEvent packet. Each **< EventID>** describes the precise relationship of the current packet to that previous VOEvent.

An **<EventID>** element has one required attribute:

3.2.1.1 ***cite*** — The ***cite*** attribute accepts three possible enumerated values, *"followup"*, *"supersedes"* or *"retraction"*. There is no default value.

The value of the ***cite*** attribute modifies the VOEvent semantics. In contrast to a VOEvent announcing a discovery (*i.e.*, a packet with no citations), a VOEvent may be explicitly a *"followup"*, citing one or more earlier packets — meaning that the described real or virtual observation was done as a response to those cited packet(s). In this case, the supplied information is assumed to be a new, independent measurement.

The ***cite*** may be *"supersedes"*, which can be used to express a variety of possible event contingencies. A prior VOEvent may be superseded, for example, if reprocessing of the original observation has resulted in different values for quantities expressed by **<What>** or **<WhereWhen>** or if the investigators have formed a new **<Hypothesis>** regarding the event. On the other hand, if a later observation has simply resulted in different measurements to report, this would typically be issued as a *"followup"*.

A *"supersedes"* ***cite*** can also be used to merge two or more earlier VOEvent threads that are later determined to be related in some fashion. The VOEvents to be merged are indicated with separate **<EventID>** elements. The proper interpretation of such a merger would depend on a VOEvent client having received all intervening packets from all relevant threads.
Finally, *"supersedes"* can be used in combination with a *"followup"* to divide a single VOEvent into two or more new threads. First, follow-up the event in one packet and then supersede the original event, rather than the follow-up, in a second packet (with a second identifier that can start a second thread).

The *"retraction"* ***cite*** indicates that the initial discovery event is being completely retracted for some reason. The publisher of a retraction may be other than the publisher of the original VOEvent — clients are free to interpret such a situation as they see fit.

Splitting, merging or retracting a VOEvent should be accompanied by a **<Description>** element discussing why such actions are being taken.

An attempt is made to retract the sighting of Tycho's supernova in 1572:

```
<Citations>
    <EventID cite="retraction">ivo://uraniborg.hven/1572-11-11/0001</EventID>
    <Description>Oops!</Description>
</Citations>
```

3.3 **<Curation>** — "Who"

This element of a VOEvent packet is devoted to curation information: who is responsible for the information content of the packet. Usage should be compatible with section 3.2 of the IVOA Resource Metadata specification [13], and with RTML 3.1 [11] for **<Contact>** metadata.

Typical curation content would include:

3.3.1 <PublisherID>

The **<PublisherID>** element contains the URI of the entity responsible for making the VOEvent available. This is a very important part of the packet, as event subscribers will often use it as their primary filtering criterion — that is, many subscribers will only want events from a particular publisher, or more precisely, content creator. In general, **<PublisherID>** should be a VOResource identifier that resolves to an organization in the sense of [13], and that will contain the curation information. If **<PublisherID>** is not resolvable, then clients are free to treat the packet however they deem appropriate.

3.3.2 <Contact>

See §4.2 for an example of usage. Also see RTML 3.1 [11].

3.3.3 <Date>

The **<Date>** contains the date & time of the creation of the VOEvent packet. The required format is ISO-8601 (*e.g.*, *yyyy-mm-dd**T**hh:mm:ss.s*, see [19]). The timescale — for curation purposes only — is assumed to be Coordinated Universal Time (UTC). Discussion of date and time for the expression of meaningful scientific coordinates may be found in [14] and [24].

Minimal **<Curation>** usage might resemble:

<Curation>

<PublisherID>ivo://uraniborg.hven</PublisherID>
<Date>1573-05-05T01:23:45Z</Date>

</Curation>

Tycho first noted SN 1572 on 11 November of that year. The event was published in Tycho's pamphlet *De Stella Nova* by 5 May 1573, thus this later date is placed in the curation metadata.

3.4 **<What>** — Event Description

The **<What>** and **<Hypothesis>** elements work together to characterize the nature of a VOEvent. That is: **<What>** was factually measured or observed to occur, versus what **<Hypothesis>** has been formed to explain this in terms of its underlying cause(s).

In general, an observation is the association of one or more dependent variables with zero or more independent variables. The **<WhereWhen>** element, for example, is often used to express the independent variables in an observation — where was the telescope pointed and when was the camera shutter opened. The **<What>** element, on the other hand, is typically used to express the dependent variables — what was seen at that location at that time.

A **<What>** element contains a list of **<Param>** elements which may be associated using **<Group>** elements. See §4.2 for an example of usage.

3.4.1 <Param> — names, values, units and ucds

<Param> elements may be used to represent the values of arbitrarily named quantities. Thus a publisher need not establish a fixed schema for all events they issue. Unified Content Descriptors (UCDs) may be used to clarify meaning. Usage of **<Param>** and **<Group>** is identical to the VOTable specification, see §4.1 of [17]; however, only the following attributes are supported for **< Param>** under VOEvent:

3.4.1.1 ***name*** — A simple utilitarian name that may be used elsewhere in the packet. This name may or may not have significance to subscribing clients.

3.4.1.2 ***value*** — A string representing the value in question. No range or type checking of implied numbers is performed.

3.4.1.3 ***unit*** — The unit for interpreting ***value***. See §4.3 of [17] which relies on [23].

3.4.1.4 ***ucd*** — A UCD expression characterizing the nature of the **<Param>**.

For example, here are three values from a GCN [3] notice:

```
TRIGGER_NUM = 114299
RATE_SIGNIF = 20.49
GRB_INTEN = 73288
```

In VOEvent, these can be represented as:

```
<Param name="TRIGGER_NUM" value="114299" />
<Param name="RATE_SIGNIF" value="20.49" ucd="stat.snr" />
<Param name="GRB_INTEN" value="73288" unit="ct" ucd="phot.count" />
```

3.4.2 <Group> — named associations

<Group> provides a simple mechanism for associating several **<Param>** elements, for instance, an error with a measurement. **<Groups>** may be nested, and each may have an optional ***name*** attribute as in §3.4.1.1.

In a GCN notice, for example, we might see this line:

```
GRB_INTEN:        73288 [cnts]     Peak=1310 [cnts/sec]
```

which could be expressed:

```
<Group name="GRB_INTEN">

    <Param name="cnts" value="73288" unit="ct" ucd="phot.count" />
    <Param name="peak" value="1310" unit="ct/s" ucd="arith.rate;phot.count" />

</Group>
```

Note that the UCDs above also carry the semantics of counts and counts per second.

The **<What>** element may be used to convey arbitrarily detailed data structures, for example, the time series that follows. Applications with more stringent time handling constraints may demand the precision provided by the use of the Space-Time Coordinate specification [14] under the **<WhereWhen>** element. In particular, a simple UCD specification offers no facility for representing a desired timescale or reference location. Typical usage might combine the expression of a series of observations using a relative timebase under **<What>** with a precise expression of spatial and temporal coordinates under the **<WhereWhen>** element, representative of the entire series of observations.

An example of specifying a simple time series:

```
<What>

    <Group>

        <Param name="mag1" ucd="phot.mag:em.opt.R" value="13.2" unit="mag" />
        <Param name="epoch1" ucd="time.epoch" value="245523.12345" unit="d" />
```

```
</Group> <Group>

        <Param name="mag2" ucd="phot.mag:em.opt.R" value="11.1" unit="mag" />
        <Param name="epoch2" ucd="time.epoch" value="245523.23456" unit="d" />

</Group> <Group>

        <Param name="mag3" ucd="phot.mag:em.opt.R" value="9.7" unit="mag" />
        <Param name="epoch3" ucd="time.epoch" value="245523.34567" unit="d" />

</Group>

</What>
```

3.5 **<WhereWhen>** — Space-Time Coordinates

The VOEvent packet may include information about where in the sky and when in time the event was detected, from what location, and may include spatial and temporal coordinate systems and errors. If the spatial or temporal locators are not present, it is to be assumed that the information is either unknown or irrelevant.

<WhereWhen> can, in general, be any legal VO STC expression, see [14]. VOEvent publishers are advised to construct expressions that concisely provide all information that is scientifically significant to the event, and no more than that. They are encouraged, though, to make the judgment as to scientific significance from the viewpoint of a wide community of potential users, not necessarily from the perspective of their own scientific interests. See §4.2 for an example of usage.

3.6 **<How>** — Instrument Configuration

The **<How>** element is used to provide instrument specific information should this be deemed necessary. It is the nature of a VOEvent to describe events in the sky, not specifically events in the focal plane of a telescope. As such, it is expected that only specialized classes of events will benefit from providing detailed information regarding the instrument. For those who may benefit from this feature, VOEvent permits the use of the RTML protocol [11] which is designed precisely to express instrumental configurations.

A **<How>** element may contain one or more **<Instrument>** elements.

3.6.1 <Instrument> — identity and configuration

Each **<Instrument>** element will typically contain a **<Name>** element, a **<Location>** element, and a **<Reference>** element (as described under §3.9). Any or all of these may be omitted. Client behavior if more than one of any of the elements is supplied is undefined.

3.6.1.1 **<Name>**
A simple string naming the instrument or instrument configuration.

3.6.1.2 **<Location>**
A simple string identifying a location associated with the instrument. This is a convenience feature — a technically precise location can be conveyed either via RTML through the **<Reference>** element below, or via STC through the **<WhereWhen>** element above.

3.6.1.3 **<Reference>** — URI reference and type
A reference URI [12] pointing to a document characterizing the instrument configuration. Pertinent values for the ***type*** attribute of **<Reference>** are *"voevent"* (*i.e.*, to borrow a previous configuration), and *"rtml"* for the normal case of specifying a detailed telescope & instrument description expressed as an RTML [11] document.

An example **<How>** element:

```
<How>

    <Instrument>

        <Name>Mosaic Camera</Name>
        <Location>Mayall 4m Telescope, Kitt Peak, AZ</Location>
        <Reference uri="ivo://nsa.noao/kp012345" type="voevent" />

    </Instrument>

</How>
```

3.7 **<Hypothesis>** — Initial Scientific Assessment

As stated in §3.4, the **<What>** (with context from **<How>**) and the **<Hypothesis>** elements work together to characterize the nature of a VOEvent. It is the job of the **<What>** element to provide strictly factual information as it is known (to whatever precision and accuracy) when the VOEvent is issued. On the other hand, it is the job of the **<Hypothesis>** element to begin the process of turning those measurements into a scientific evaluation of the nature of the object or process under consideration.

<Hypothesis> seeks to capture the publisher's emerging concept of the nature of the astronomical objects and processes that caused the observations noted in the **<What>** element. Natural language words and phrases are used to express the hypothesized astrophysics, pending a standard VO ontology or formal UCD-like vocabulary of astronomical concepts (see [15] and [16], for example).

A **<Hypothesis>** element contains one or more **<Classification>** elements. These may be used to assert concepts that *classify* the type of an event (*e.g.*, *"the event is a supernova"*), or rather that *identify* the event with some specific astronomical object or feature (*"the supernova went off in NGC1234"*). Each **<Classification>** may be associated with an estimate of its likelihood. The **<Importance>** element provides an optional rating of the relative noteworthiness of the event.

3.7.1 <Classification> — classes, identities and probabilities

A **<Classification>** element has one (optional) attribute and contains any number of **<Class>** and/or **<Identity>** elements:

3.7.1.1 ***probability*** — The optional ***probability*** attribute provides an estimate of the likelihood that a particular classification or identification is correct. It is expressed as an integer percentage from 0 to 100. A value of 0, for instance, can be used to eliminate options from further consideration.

3.7.1.2 **<Class>**
A natural language characterization of the type of astronomical object(s) or process(es) that generated the event. It is expected that this will be replaced or supplemented in a future version of VOEvent with a formal UCD (or UCD-like) vocabulary or VO-standard astronomical ontology.

3.7.1.3 **<Identity>**
The name of an astronomical object deemed to be associated (*e.g.*, positionally) with the event being characterized. Pending the availability of a rich astronomical ontology, the precise nature of this association will be described in natural language statements. Preferred usage is to restrict the value of **<Identity>** to standard astronomical nomenclature, for example, as recognized by NED [20] or SIMBAD [21].

Until a standard astronomical ontology is available, preferred usage would be to embed the natural language descriptions of **<Class>** and **<Identity>** within **<Description>** elements.

3.7.2 <Importance> — the noteworthiness of the event

The **<Importance>** element provides an optional rating of the "importance" of the VOEvent, expressed as an integer percentage using the ***value*** attribute. The ***value*** is bounded inclusively between 0 and 100. The meaning of **<Importance>** is unspecified other than that larger values are considered of generally greater importance. The publishers of each category of event are encouraged, however, to develop a self-consistent rating scheme. A subscriber may choose to consider the importance rating from a particular publisher in combination with other VOEvent metadata in deciding the urgency of the alert for the subscriber's purposes. A **<Description>** may be appropriate to discuss the implications of a particularly large **<Importance>**.

3.7.2.1 ***value*** — The ***value*** attribute provides an estimate of the "importance" of a particular event. It is expressed as an integer percentage between 0 and 100.

An example **<Hypothesis>** with multiple **<Classifications>**:

```
<Hypothesis>

    <Classification probability="100">

        <Identity>Tycho's Stella Nova</Identity>
        <Class>SN Ia</Class>

    </Classification>
    <Classification probability="100">

        <Identity>3C 10</Identity>
        <Class>supernova remnant</Class>

    </Classification>
    <Importance value="100" />

</Hypothesis>
```

3.8 **<Description>**

This optional element permits the VOEvent packet to contain additional human-readable information of unspecified format. A **<Description>** may be included within any element or sub-element of a VOEvent to add human readable content. **<Descriptions>** may contain **<References>** and vice versa, for instance, to allow a client to recognize a URL embedded in an otherwise only human-readable block of text.

3.9 >**<Reference>**

A **<Reference>** may be included in any element or sub-element of a VOEvent packet to describe an association with external content via a Uniform Resource Identifier [12]. The type of the URI may be explicited provided to ease handling and speed access. A short local name may be attached to the global resource. Any text attached to a **<Reference>** is taken to be natural language description of the meaning of the citation.

It is anticipated that VOEvent packets will often include **<References>** to such content as finding charts, cut-out images, light-curves, object catalogs, SQL queries, instrumental configurations — to list only a few. This content will be expressed in various graphics and image formats such as FITS, as VOTables [17], as RTML [11] documents, as MIME-typed web content in general, or as native VOEvents.

A **<Reference>** element has three attributes:

3.9.1.1 ***uri*** — The identifier of another document.

3.9.1.2 ***type*** — The type of the document. Allowed values are *"voevent"*, to reference a previously issued VOEvent packet (in whole or in part) — *"url"*, for a MIME-typed URL — *"rtml"*, to refer to an RTML [11] document (typically the one used to drive the telescope that made the observation(s) resulting in the event), or — *"ivo"*, to refer to IVO resources. The value of ***type*** is case insensitive.

3.9.1.3 ***name*** — A short, optional name to be used in descriptive text.

An example of the indirection of a VOEvent packet using **<Reference>** (also see §4.3):

<VOEvent id="ivo://raptor.lanl/235649409/sn2005k" role="actual" version="0.90">

<Reference uri="http://www.raptor.lanl.gov/documents/event233.xml" type="voevent" />

</VOEvent>

4: VOEvent Examples

4.1 A simple VOEvent packet

This VOEvent packet is an imaginary report from the Raptor project at Los Alamos, that a magnitude 13 star was seen at RA=148.888, Dec=69.065, with an error radius of 0.1 degrees. It is reported as "fast orphan optical transient", so we infer that the same source was not seen in that position before.

```
<?xml version="1.0" encoding="UTF-8"?>
<VOEvent id="ivo://raptor.lanl/235649409/sn2005k" role="actual" version="0.90"
  xmlns:stc="http://www.ivoa.net/xml/STC/stc-v1.22.xsd"
  xmlns:crd="http://www.ivoa.net/xml/STC/STCcoords/v1.22"
  xmlns:xi="http://www.w3.org/2001/XInclude"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://www.ivoa.net/xml/STC/stc-v1.22.xsd stc-v1.22.xsd">

  <Curation>
    <PublisherID>ivo://raptor.lanl/</PublisherID>
    <Date>2005-04-15T14:34:16</Date>
  </Curation>

  <WhereWhen>
    <stc:ObservationLocation>
      <xi:include href="http://www.ivoa.net/xml/STC/FK5-UTC-TOPO.xml"/>
      <crd:AstroCoords coord_system_id="FK5-UTC-TOPO">
        <crd:Time unit="s">
          <crd:TimeInstant>
            <crd:ISOTime>2005-04-15T23:59:59</crd:ISOTime>
          </crd:TimeInstant>
        </crd:Time>
        <crd:Position2D unit="deg">
          <crd:Value2>148.888 69.065</crd:Value2>
          <crd:Error2Radius>0.1</crd:Error2Radius>
        </crd:Position2D>
      </crd:AstroCoords>
    </stc:ObservationLocation>
  </WhereWhen>
  <What>
    <Param name="magnitude" ucd="phot.mag:em.opt.R" value="13.2" />
  </What>

  <Hypothesis>
    <Classification probability="30">
      <Class>Fast Orphan Optical Transient</Class>
    </Classification>
```

```
  </Hypothesis>
</VOEvent>
```

4.2 A typical VOEvent packet

This is a somewhat more comprehensive example. Again, the publisher is Raptor, although the "What" section seems to be about gamma-photon counts where the seeing is poor (!). The packet represents a followup observation of an earlier event, as defined in the citation section. The position is stated with an error ellipse with axes 0.02 and 0.01, and position angle is 15 degrees. The time of the event has an error estimate of one second; also the observatory position is given through an included document at the top of the WhereWhen section.


```
<?xml version="1.0" encoding="UTF-8"?>
<VOEvent id="ivo://raptor.lanl/235649409/followup3" role="actual" version="0.90"
  xmlns:stc="http://www.ivoa.net/xml/STC/stc-v1.22.xsd"
  xmlns:crd="http://www.ivoa.net/xml/STC/STCcoords/v1.22"
  xmlns:xi="http://www.w3.org/2001/XInclude"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://www.ivoa.net/xml/STC/stc-v1.22.xsd stc-v1.22.xsd">

  <Citations>
    <EventID cite="followup">ivo://raptor.lanl/235649409</EventID>
    <Description>
      This is an observation of the earlier event but
      with improved square-galaxy discrimination
    </Description>
    <Reference
      uri="http://raptor.lanl.gov/data/lightcurves/235649409" type="url">
      This is the light curve associated with the observation.
    </Reference>
  </Citations>

  <Curation>
    <PublisherID>ivo://raptor.lanl/</PublisherID>
    <Contact principleContact="true">
      <Name>Robert White</Name>
      <Institution name="LANL" />
      <Communication>
 <AddressLine>
   Los Alamos National Laboratory
   PO Box 1663
   ISR-1, MS B244
   Los Alamos, NM 87545
 </AddressLine>
      </Communication>
      <Telephone>+1-505-665-3025</Telephone>
      <Email>rwhite@lanl.gov</Email>
    </Contact>
    <Date>2005-04-15T14:34:16</Date>
  </Curation>

  <What>
    <Group name="SQUARE_GALAXY_FLUX">
      <Param name="counts" value="73288" unit="ct" ucd="phot.count">
      <Param name="peak" value="1310" unit="ct/s" ucd="arith.rate;phot.count">
    </Group>
    <Param name="seeing" value="2" unit="arcsec" ucd="instr.obsty.site.seeing" />
  </What>

  <WhereWhen>
    <xi:include href="http://www.raptor.gov/documents/raptor.xml"/>
    <stc:ObservationLocation>
      <xi:include href="http://www.ivoa.net/xml/STC/FK5-UTC-TOPO.xml"/>
      <crd:AstroCoords coord_system_id="FK5-UTC-TOPO">
        <crd:Time unit="s">
```

```
            <crd:TimeInstant>
              <crd:ISOTime>2005-04-15T23:59:59</crd:ISOTime>
            </crd:TimeInstant>
            <crd:Error>1.0</crd:Error>
          </crd:Time>
          <crd:Position2D unit="deg">
            <crd:Value2>148.88 69.06</crd:Value2>
            <crd:Error2PA>
              <crd:Size>0.02 0.01</crd:Size>
              <crd:PosAngle reference="North">15</crd:PosAngle>
            </crd:Error2PA>
          </crd:Position2D>
        </crd:AstroCoords>
      </stc:ObservationLocation>
    </WhereWhen>

    <How>
      <Instrument>
        <Name>Raptor AB</Name>
        <Location>Los Alamos</Location>
        <Reference uri="http://www.raptor.lanl.gov/documents/phase_zero.rtml" type="rtml" />
      </Instrument>
    </How>

    <Hypothesis>
      <Classification probability="30">
        <Class>Fast Orphan Optical Transient</Class>
      </Classification>
      <Classification>
        <Identity>NGC1234</Identity>
      </Classification>
      <Importance value="80" />
    </Hypothesis>
  </VOEvent>
```

4.3 A VOEvent "pointer" indirection packet

The **<Reference>** element provides a publisher with the capability to distribute a very lightweight alert consisting of a pointer to a stored event packet. The ***id*** is set to the ***id*** of the original packet, allowing an intervening client such as an aggregator to persist the ***id*** in a backend database. Since the **<Reference>** ***type*** is explicitly declared, the contents of the packet can later be verified directly against expectations, requiring no preliminary classification of the packet.

```
<?xml version="1.0" encoding="UTF-8"?>
<VOEvent id="ivo://raptor.lanl/235649409/sn2005k" role="actual" version="0.90">
   <Reference uri="http://www.raptor.lanl.gov/documents/event233.xml" type="voevent" />
</VOEvent>
```

5. References

Some event alert networks:

1. ATEL: *The Astronomer's Telegram*
   http://www.astronomerstelegram.org
2. CBAT: *Central Bureau for Astronomical Telegrams*
   http://cfa-www.harvard.edu/iau/cbat.html, or
   http://cfa-www.harvard.edu/iau/DiscoveryInfo.html (discovery schema)
3. GCN: *The Gamma-Ray Burst Coordinates Network*
   http://gcn.gsfc.nasa.gov
4. VOEvent: *IVOA Sky Transient Metadata*
   http://www.ivoa.net/twiki/bin/view/IVOA/IvoaVOEvent, or
   http://www.ivoa.net/twiki/bin/view/IVOA/VoeventWorkshop (original workshop, 2005)

Some surveys reporting events (or planning to):

5. LIGO: *Laser Interferometer Gravitational Wave Observatory*
   http://www.ligo.caltech.edu
6. LSST: *Large Synoptic Survey Telescope*
   http://www.lsst.org
7. Palomar-QUEST: *A case study in designing sky surveys in the VO era*
   http://resolver.caltech.edu/CaltechCACR:2004.218
8. Pan-STARRS: *the Panoramic Survey Telescope & Rapid Response System*
   http://pan-starrs.ifa.hawaii.edu/public/index.html
9. Swift: *Catching Gamma-Ray Bursts on the Fly*
   http://swift.gsfc.nasa.gov/docs/swift/swiftsc.html

Robotic telescope infrastructure:

10. ROBOT: A list of robotic telescope projects:
    http://www.astro.physik.uni-goettingen.de/~hessman/MONET/links.html
11. RTML: *Remote Telescope Markup Language*
    http://www.uni-sw.gwdg.de/~hessman/RTML, or
    http://monet.uni-goettingen.de/twiki/bin/view/RTML (twiki)

VO standards:

12. ID: *IVOA Identifiers*
    http://www.ivoa.net/Documents/latest/IDs.html
13. RM: *Resource Metadata for the Virtual Observatory*
    http://www.ivoa.net/Documents/latest/RM.html
14. STC: *Space-Time Coordinates Metadata for the Virtual Observatory*
    http://www.ivoa.net/Documents/latest/STC.html
15. UCD: *Unified Content Descriptor*
    http://www.ivoa.net/Documents/latest/UCD.html, or
    http://cdsweb.u-strasbg.fr/UCD
16. VOConcepts: *a proposed UCD for Astronomical Objects, Events, and Processes*
    http://monet.uni-sw.gwdg.de/twiki/bin/view/VOEvent/UnifiedContentDescriptors
17. VOTable: *Format Definition*
    http://www.ivoa.net/Documents/latest/VOT.html
18. XML: *Extensible Markup Language*
    http://xml.coverpages.org/xml.html, and
    http://xml.coverpages.org/schemas.html, or
    http://www.ucc.ie/xml (FAQ)

Astronomical resources:

19. ISO 8601: *standard representation of dates and times*
    http://www.cl.cam.ac.uk/~mgk25/iso-time.html
20. NED: *NASA/IPAC Extragalactic Database*
    http://nedwww.ipac.caltech.edu/
21. SIMBAD: *Set of Identifications, Measurements and Bibliography for Astronomical Data*
    http://simbad.u-strasbg.fr/Simbad
22. TYCHO: *De Stella Nova*
    http://www.texts.dnlb.dk/DeNovaStella/Index.html (in Danish)
23. UNITS: *Standards for Astronomical Catalogues: Units*
    http://vizier.u-strasbg.fr/doc/catstd-3.2.htx
24. UTC: *the future of Coordinated Universal Time*
    http://www.ucolick.org/~sla/leapsecs

Appendix: Existing event systems

Several systems already exist for notification of immediate astrophysical effects. The earliest is the Central Bureau for Astronomical Telegrams of the International Astronomical Union (IAU); another is the Gamma-ray Burst Coordinate Network that is associated with satellites that detect GRBs. The Astronomer's Telegram system is more general, and has been successful for a number of years; the

RealTime Virtual Observatory (RTVO) is building the database and messaging structures that will be necessary for robotic event-driven astronomy. Finally, we mention the Remote Telescope Markup Language (RTML), which is a sophisticated schema for defining the sequencing and state of an optical telescope.

1 Central Bureau of Astronomical Telegrams

The Central Bureau for Astronomical Telegrams (CBAT), under the auspices of the International Astronomical Union (IAU), is a nonprofit organization, with principal funding coming from subscriptions to the various services offered by the Bureau. The CBAT is responsible for the dissemination of information on transient astronomical events, via the IAU Circulars (IAUCs), a series of postcard-sized announcements issued at irregular intervals as necessary in both printed and electronic form. Messages announce new discoveries of supernovae, novae, comets, satellites of major/minor planets, and other interesting transient astronomical objects (particularly those that are unusual, such as cataclysmic variables that have outbursts less frequently than once every year or two, or very unusual variable stars or non-stellar objects

The schema for an IAU Telegram is:

- Name
- Postal address and contact details
- Date and UT time of observation
- Observation method (e.g., naked eye, visual telescopic observation, photographic, or telescopic CCD)
- Instrumentation (aperture size, f/-ratio, etc.) and exposures (type of film or CCD, length of exposure, etc.)
- Observation site
- Text description

In addition to this general information, each of several classes of event has a specific schema. For details, see the reference below. These classes of event are: [Comets, Supernovae, Novae, Outbursts Of Unusual Variable Stars, Features On Planetary Surfaces].

2 Gamma-ray Burst Coordinate Network

The GCN system has the capability to receive_from and distribute_to the GRB research community timely information on GRBs (called GCN Circulars). These reports are in the prose-style (as opposed to the highly formated "TOKEN: value"-style of the original GCN Notices). The process is simple. People can e-mail their reports to a central location and then those reports will be automatically distributed to a list of people. This list of Circular recipients is completely separate from the list of Notice recipients.

These GCN Observation Report Circulars will allow the GRB follow-up community to make optimum use of its limited resources (labor and telescope time) by communicating what has already been done or will soon be done. This facility is also fast (~1min) and cheap (0$) for the submitter.

The schema for a GCN packet is:

- Title
- GRB number (format is YYMMDD)
- Subject
- Date of report
- Name and email of submitter
- Text description (HTML)

3 Astronomer's Telegram

The Astronomer's Telegram (ATEL) is for the reporting and commenting upon new astronomical observations of transient sources. In addition to the Telegram Index on the web, readers may request a Daily Email Digest (see Email Options). Readers select those subject areas of interest, and Telegrams marked with those subject headings will be mailed to them after each 24-hr period (no email will be sent if no such Telegrams are received). Readers may also request the Instant Email Notices, used to report the discovery, with coordinates, of one of several different types of objects, as well as new outbursts of previously known transients. The Instant Email Notices also include a "Request for Observations", which provides alerts of observational opportunities in the coming 72 hours. The Instant Email Notices are sent immediately (within a few seconds) upon receipt. Reports submitted to The Astronomer's Telegram are not filtered or edited: the final editing on all submissions is made by the author. Submissions are posted onto the web instantly, by software.

The schema for an ATEL packet is:

- Author
- Email
- Telegram Title
- Text description (HTML)
- Link URL, and Link title are optional.
- Waveband: may be any subset of [Radio, Millimeter, Sub-Millimeter, Far-Infra-Red, Infra-Red, Optical, Ultra-Violet, X-ray, Gamma Ray, >GeV]
- Object attributes, may be any subset of [Request for Observations , A Comment, AGN, Asteroids, Binaries, Black Holes, Comets, Cosmic Rays, Cataclysmic Variables, Globular Clusters, Gamma-Ray Bursts, Meteors, Microlensing Events, Neutron Stars, Nova, Planets, Planets (minor), Pulsars, Quasars, Soft Gamma-ray Repeaters, Solar System Objects, The Sun, Supernova, Supernova Remnants, Transients, Variables, Stars].

4 Remote Telescope Markup Language

Remote Telescope Markup Language (RTML) [11] is an XML-based protocol for the definition and exchange of telescope observing requests. The further development of RTML is being pushed by many wishes, constraints, and needs, particularly the capability: to support more complicated requests, instruments, and observing constraints; to support the "charging" of telescope time against user and external network accounts; to let the requests evolve as more information becomes available; and to use RTML documents to fully document the complete evolution of a request from the planning stage, the definition of the request in all its detail, the description of the actual observation, and all the way to the final delivery of data to the original client/user. The primary elements of an RTML description are: project description (including contact information), choice of generic or specific telescope+instrument (*e.g.*, camera, spectrograph), and detector; choice of exposure time; description of scheduling constraints; and catalogue/target information. There may also be information on how the retrieved information was processed (*e.g.*, calibration, pipeline, etc).

We are evaluating the RTML as a candidate for describing telescopic observations in a more general way than is intended in the "instrument configuration" schema mentioned above. Other instruments might build custom schemas, for example the LIGO gravitational wave detector probably would not use RTML to describe instrument configuration.

5 RTVO.net

This new system is an attempt to make a prototype event database, featuring XML message format, subscription services, an XML database to hold the event descriptions, and IVOA identifiers for the events themselves.

Changelog

- Chris Stoughton — October 11, 2004

1. change precision of coordinates and time from float to double
2. the time data structure needs system and precision
3. added some packetTypes, not sure if this is the right place. For one neutrino burst every 100 years, we don't need to worry about a veto or error, but when LSST generates a bazillion events each night, we need a triage system. Just as you can decide whether to pay attention to a group's discoveries, you can also decide whether to pay attention to some other group's veto, merge, and reject suggestions.
4. Questions:
   - Events on solar system bodies: volcanoes on Io, impacts on the Moon, Solar flares, and so on.
   - Do you want to be more explicit about what you expect to happen next with this document? You mention in the first bullet point in the Introduction that "representative of projects are expected to assess the usefulness of this message against their intended use." It may be more effective to have a more explicit call to action.

- Roy Williams — November 18, 2004
  1. change references to "transients" to "events"
  2. modified abstract for clarity
  3. added "Nature of event" section
- Roy Williams — December 2004
  1. Added section 5 on existing systems
- Rob Seaman — April 2005
  1. edited abstract and intro to reflect VOEvent workshop discussion
  2. moved §5 to appendix B (verbatim)
  3. merged §4 and part of §1 into §2
  4. expanded and organized list of references (as §4)
  5. added appendix A with examples from workshop, fiddled with indents
  6. expanded list of authors
  7. edited §2 lightly, removed figure
  8. added to references, started referring to these in the text
  9. added introductory material to §3, rearranged subheadings
  10. edited for style throughout, document in desired sequence
  11. updated §3 to match workshop examples
  12. released as v0.4
- Frederic Hessman — May 2005
  1. Lots of things which need to be listed here!
  2. released as v0.5
- Rob Seaman — 5 May 2005
  1. Merged most changes from Hessman, rejected a few, reworded others.
  2. edited for content and style
  3. released as v0.6_draft1
- Rob Seaman — 6 May 2005
  1. edits to text per A. Rots, corrected URL for STC documentation
  2. added *units* attribute to <Param>
  3. added <Importance> to <Hypothesis>
  4. slight edits to abstract and §2, and for style throughout
  5. added indenting to §3 for clarity
  6. added CDS Units reference
  7. checked spelling (not in appendices)
  8. document now has Unix newlines (LF), rather than original windows CR-LF or MacOS CRs.
  9. released as v0.6_draft2
- Rob Seaman — 7 May 2005
  1. further improvements to phrasing in abstract and intro
  2. style of §3 updated to improve readability
  3. added examples through §3.3
- Roy Williams — 10 May 2005
  1. Unified references between VOEvent refs and general citations: Ref now has uri, name, type, and relation attributes

2. removed much of the hypothesis section formal vocabulary, it seesm too immature for the moment
3. cross-checked examples with text
4. general phrasing and text, some examples added
5. renamed and moved Appendix A as section 4

- Rob Seaman — 10-11 May 2005
  1. edited for style and grammar
  2. merged examples and formatting of §3
  3. added to and reorganized references
  4. simplified hypothesis to use natural-language
  5. added global reference element
  6. corrected Publisher to PublisherID
  7. Event is now EventID
  8. various adjustments, including to examples, to bring document into agreement with emerging baseline consensus on all points
  9. released as v0.62
- Rob Seaman — 12 May 2005
  1. incorporated comments from A. Rots
  2. rearranged §2
  3. released as v0.63
- Rob Seaman — 12-13 May 2005
  1. incorporated changes from Rick Hessman:
  2. - Added hyperlinks to references
  3. - edited for style and grammar
  4. - Made <Contact> compatible with RTML 3.1
  5. added additional internal links
  6. updated version to 0.90 in examples
  7. released as v0.90