Sky Event Reporting Metadata (*VOEvent*) Version 0.94

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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 implication that timely follow-up is being requested. The objective is 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 (a "why") 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 from discovery through successive follow-ups.

VOEvent packets gain persistent identifiers and are typically stored in databases reached via registries. VOEvent packets may therefore reference other packets in various ways. Subscribers, human or machine, receive immediate notification of events, based on previously defined criteria. Packets are required to be small and to be processed quickly. This standard does not define a transport layer or the design of clients, registries or aggregators; it 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, with new survey telescopes 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, as well as 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 follow-up observation — perhaps the immediate acquisition of the spectrum of a suspected 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. These include RAPTOR [13] at the Los Alamos National Laboratory and RoboNet-1.0 [12] in the United Kingdom which relies upon the eSTAR [11] network. Automated systems may also query archives and initiate pipelines in response to such alerts.

Many projects have been conceived — 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 [8], Pan-STARRS [9] and LSST [7], satellites like Swift [10], and more singular experiments like LIGO [6]. The community has demonstrated that robotic telescopes [14] 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 follow-up 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 indicate events that must be handled by machines, not humans. Subscribing agents must be able to automatically filter 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 register with multiple instruments.

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 [33] 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 [18] or the Remote Telescope Markup Language (RTML) [15].

VOEvent is a pragmatic effort that crosses the boundary between the Virtual Observatory and the larger astronomical community. The results of 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 follow-up, and this purpose defines its scope. An astronomical discovery that cannot benefit from immediate follow-up 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 "why" 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 [5] 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 [16]. 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 that will 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 will 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 E-mail 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 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.

2.3 Authentication and Authorization

VOEvents provide a mechanism for alerting members of the astronomical community to time-critical celestial phenomena. As a result of such an alert, significant hardware, software and personnel assets of the community may be retargeted to investigate those phenomena. The scientific and financial costs of such retargeting may be large, but the potential scientific gains are larger. The success of VOEvent — and of observations of astronomical transients in general — depends on minimizing both intentional and unintentional "noise" associated with this communications channel. All of the familiar internet security worries apply to VOEvents.

Authorization is a question of controlling who may receive the information contained in an event stream or in a specific VOEvent. This is perceived to be purely a function of the transport layer through which VOEvents are delivered from publisher to subscriber. As such, VOEvent access authorization is outside the scope of this specification. On the other hand, the authentication of messages is a matter of extending trust outward from the publisher of a packet to any client who later receives that packet. How may a subscriber be confident that the apparent origin of a packet was the actual origin of the packet? How may a subscriber be confident that the packet was not modified in transit?

Where authorization is concerned with limiting user access, authentication is concerned precisely with enabling trust in unfettered access. It is likely that some future version of VOEvent will benefit from a general purpose VO authentication standard. VOEvent packets will often be distributed through unofficial as well as official channels — for example, one astronomer may forward a VOEvent of interest to another via E-mail. This is not only behavior that cannot be avoided, it is behavior that should be encouraged via solid support for authentication.

Some predictions are clear regarding future VO security standards and practices — others are hazy at best. The VO is likely to adopt widely recognized network standards such as SSL [32] and S-HTTP [31] to secure transport channels. SAML [30] may be used to distribute security assertions based on X.509 [34] certificates. The precise semantics are unclear, however, for providing support for these standards within VO documents. It is non-trivial (or impossible) to directly embed a digital signature within a document since the signature changes the document (see [27]). The identifier of a document might be used to retrieve a security certificate from a remote database via a chain of registries; alternately, a document might contain an explicit pointer to such a certificate, *e.g.*, to a PGP [29] digital signature. In the case of VOEvent, diverse possibilities suggest themselves. References to external security certificates could be provided via explicit **<Reference>** elements, via *"followup"* **<Citations>**, via some extension to the **<Who>** curation schema, via a VOEvent ***id*** database or registry query, or perhaps via an entirely new **<Authentication>** sub-element that responds to a broader VO standard. It is premature for the current version of the VOEvent specification to mandate future usage in this area.

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 [5] 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 one of each of the following sub-elements:

<Who>	*Curation Metadata*
<What>	*Event Characterization*
<WhereWhen>	*Space-Time Coordinates*
<How>	*Instrument Configuration*
<Why>	*Initial Scientific Assessment*
<Citations>	*Follow-up Observations*
<Description>	*Human Oriented Content*
<Reference>	*External Content*

Alternately, a **<VOEvent>** element may be completely empty except for a single **<Reference>** element used to express an indirection of the packet. The ***id*** of such an indirected VOEvent packet should be set to the that of the referenced packet (see §3.9).

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. At most one sub-elements of each type may be included in a single VOEvent — 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 should be used with care within a **<VOEvent>** element. Section 4 contains examples of complete VOEvent packets.

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

A **<VOEvent>** expresses the discovery of a sky transient event, located in a region of space and 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.

The **<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 [16]. As the issuance of duplicate identifiers would diminish the trust placed in systems exchanging VOEvents, it is anticipated that a number of VOEvent publishers will be founded to issue unique IDs from a variety of useful and appropriate namespaces.

3.1.2 *role* — The optional ***role*** attribute accepts three possible enumerated values: *"observation"*, *"prediction"*, or *"test"*. The value *"observation"* is the default if the ***role*** is missing; this means that the packet describes an observation of the actual universe. The value *"prediction"* indicates that the VOEvent describes an event of whatever description that has yet to occur when the packet is created. A *"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 or a prediction of an event that has yet to happen.

3.1.3 *version* — The ***version*** attribute is required to be present and to equal "0.94" 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 [24] might start:

<VOEvent id="ivo://uraniborg.hven/1572-11-11/0001" role="observation" version="0.94" 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 **<Who>** — Curation Metadata

This element of a VOEvent packet is devoted to curation metadata: who is responsible for the information content of the packet. Usage should be compatible with section 3.2 of the IVOA Resource Metadata specification [17], and with RTML 3.1 [15] for **<Contact>** metadata.

Typical curation content would include:

3.2.1 <PublisherID>

The **<PublisherID>** element contains the URI of the entity responsible for making the VOEvent available. Event subscribers will often use this as their primary filtering criterion. Many subscribers will only want events from a particular publisher, or more precisely, from a specific content creator. In general, **<PublisherID>** should be a VOResource identifier that resolves to an organization in the sense of [17]. Publishers and subscribers may use this VOResource to exchange curation metadata directly.

3.2.2 <Contact>

See §4.2 for an example of usage. Also see RTML 3.1 [15].

3.2.3 <Date>

The **<Date>** contains the date and 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 [28]). 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 [18] and [26].

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

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

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. More detailed curation metadata can be retrieved directly from the publisher.

3.3 **<What>** — Event Characterization

The **<What>** and **<Why>** elements work together to characterize the nature of a VOEvent. That is: **<What>** was factually measured or observed to occur, versus **<Why>** in terms of its hypothesized 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 and labeled using **<Group>** elements. See §4.2 for an example of usage.

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

<Param> elements may be used to represent the values of arbitrarily named quantities. A **<Param>** must be expressed as an empty element. Thus a publisher need not establish a fixed schema for all events they issue. Unified Content Descriptors (UCDs) [19] may be used to clarify meaning. Usage of **<Param>** and **<Group>** is similar to the VOTable specification, see §4.1 of [21]; however, only the following attributes are supported for **<Param>** under VOEvent:

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

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

3.3.1.3 ***unit*** — The unit for interpreting ***value***. See §4.3 of [21] which relies on [25].

3.3.1.4 ***ucd*** — A UCD [19] 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" />
```

3.3.2 <Group> — named associations

<Group> provides a simple mechanism for associating several **<Param>** (and/or **<Reference>**) elements, for instance, an error with a measurement. **<Groups>** may NOT be nested. **<Group>** elements may have a ***name*** attribute, and unlike VOTable usage, may also have a ***type*** attribute:

3.3.2.1 ***name*** — A simple name such as in §3.3.1.1.

3.3.2.2 ***type*** — A string that can be used to specify the "datatype" of simple application dependent data structures.

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

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

which could be expressed:

```
<Group type="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 [18] 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. Applications with more stringent space or time coordinate handling requirements yet, may require successive follow-up packets be issued to correctly capture the dependency of **<What>** upon **<WhereWhen>** for each individual observation in a series or multi-site observation.

An example of specifying a simple time series:

```
<What>
    <Group type="phot_pt" >
        <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 type="phot_pt" >
        <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 type="phot_pt" >
        <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>
```

3.4 **<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 [18]. 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.

3.5 **<How>** — Instrument Configuration

The **<How>** element supplies instrument specific information. A VOEvent describes events in the sky, not events in the focal plane of a telescope. Only specialized classes of event will benefit from providing detailed information about instrumental or experimental design. A **<How>** contains zero or more **<References>** (see §3.9) to RTML documents [15] characterizing the instrument(s) that produced the observation(s) that resulted in issuing the VOEvent packet. A URI pointing to a previous VOEvent asserts that an identical instrumental configuration was used:

```
<How>
        <Reference uri="http://nsa.noao.edu/kp012345.rtml" type="rtml" name="Echelle" />
</How>
```

3.6 **<Why>** — Initial Scientific Assessment

<Why> seeks to capture the emerging concept of the nature of the astronomical objects and processes that generated 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 [19] and [20], for example). The **<Why>** element has two optional attributes, ***importance*** and ***expires***, providing ratings of the relative noteworthiness and urgency of each VOEvent, respectively. Subscribers should consider the ***importance*** and ***expires*** ratings from a particular publisher in combination with other VOEvent metadata in interpreting an alert for their purposes. The publishers of each category of event are encouraged to develop a self-consistent rating scheme for these values.

3.6.1 *importance* — The ***importance*** provides a rating of the noteworthiness of the VOEvent, expressed as a floating point number bounded between 0.0 and 1.0 (inclusive). The meaning of ***importance*** is unspecified other than that larger values are considered of generally greater importance.

3.6.2 *expires* — The ***expires*** attribute provides a rating of the time-criticality or urgency of the VOEvent, expressed as an ISO-8601 [28] representation of some date and time in the future. The meaning of ***expires*** is application dependent but will often represent the date and time after which a follow-up observation might be belated.

A **<Why>** element contains one or more **<Concept>** and **<Name>** sub-elements. These may be used to assert concepts that specify a scientific classification of the nature of the event, or rather that attach the name of some specific astronomical object or feature. These are organized using the **<Inference>** element, which permits expressing the nature of the ***relation*** of the contained elements to the event in question. Each **<Inference>** may also provide an estimate of its likelihood via a ***probability*** attribute.

3.6.3 <Concept> — classification

The value of a **<Concept>** element uses natural language words and phrases to express the hypothesized astrophysics, pending a standard VO ontology or formal UCD-like vocabulary of astronomical concepts (see [19] and [20], for example).

3.6.4 <Name> — identification

<Name> provides the name of a specific astronomical object. It is preferred, but not required, to use standard astronomical nomenclature, *e.g.*, as recognized by NED [22] or SIMBAD [23].

3.6.4 <Inference> — hypotheses inferred

An **<Inference>** may be used to group or associate one or more **<Name>** or **<Concept>** elements. **<Inference>** has two optional attributes, ***probability*** and ***relation***:

3.6.4.1 ***probability*** — The ***probability*** attribute is an estimate of the likelihood of the **<Inference>** accurately describing the event in question. It is expressed as a floating point number bounded between 0.0 and 1.0 (inclusive). In particular, note that a ***probability*** of 0.0 can be used to eliminate **<Inferences>** from further consideration.

3.6.4.2 ***relation*** — The ***relation*** attribute is a natural language string that expresses the degree of connection between the **<Inference>** and the event described by the packet.

This example asserts that the creator of the packet is 100% certain that the event being described is equivalent to *Tycho's Star*, which has been identified as a *Type Ia Supernova*, and is associated with the *SN remnant* known as *3C 10*. This was an important discovery, but is no longer a very urgent one:

```
<Why importance="1.0" expires="2000-01-01T12:00:00">
    <Inference probability="1.0">
        <Name>Tycho's Stella Nova</Name>
        <Concept>SN Ia</Concept>
    </Inference>
    </Inference probability="1.0" relation="associated">
        <Name>3C 10</Name>
        <Concept>supernova remnant</Concept>
    </Inference>
</Why>
```

3.7 **<Citations>** — Follow-up Observations

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 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.

3.7.1 <EventID> — references and cites

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

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

3.7.1.1 ***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 **<Why>** 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 typically 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:

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

3.8 **<Description>** — Human Oriented Content

A **<Description>** may be included within any element or sub-element of a VOEvent to add human readable content. **<Descriptions>** may NOT contain **<References>**, and in general, publishers should assume that subscribers will ignore any embedded XML tags, with the exception of HTML style layout of CDATA fields.

3.9 **<Reference>** — External Content

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 [16]. The type of the URI is explicitly specified to ease handling and speed access. A short local name may be attached to the global resource. A **<Reference>** must be expressed as an empty element.

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 [21], as RTML [15] documents, as MIME-typed web content in general, or as native VOEvents.

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

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

3.9.2 ***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 [15] 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.

3.9.3 ***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="observation" version="0.94">
    <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 [13] at Los Alamos National Lab, 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", and it may thus be inferred 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="observation" version="0.94"
  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">

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

    <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>

    <Why>
      <Concept>Fast Orphan Optical Transient</Concept>
    </Why>
  </VOEvent>
```

4.2 A typical VOEvent packet

This is a somewhat more comprehensive example. Again, the publisher is RAPTOR [13], although the **<What>** sub-element seems to be about photon counts with poor seeing. The packet represents a follow-up observation of an earlier event, as defined in the **<Citations>** element. 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 **<WhereWhen>** (see §3.4).

```
  <?xml version="1.0" encoding="UTF-8"?>
  <VOEvent id="ivo://raptor.lanl/235649409/followup3" role="observation" version="0.94"
    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>

  <Who>
    <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>
  </Who>

  <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>
    <Reference uri="http://www.raptor.lanl.gov/documents/phase_zero.rtml"
      type="rtml" name="Raptor AB">
      This VOEvent packet resulted from observations made with Raptor AB at Los Alamos.
    </Reference>
  </How>

  <Why importance="0.8" expires="2005-04-16T02:34:16" >
    <Concept>Fast Orphan Optical Transient</Concept>
    <Inference relation="associated">
```

```
        <Name>NGC1234</Name>
      </Inference>
    </Why>
</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="observation" version="0.94">
   <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. rtVO: *The real-time Virtual Observatory*
   http://www.rtvo.net
5. VOEvent: *IVOA Sky Transient Metadata*
   http://monet.uni-sw.gwdg.de/twiki/bin/view/VOEvent (schema)
   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):

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

Robotic telescope infrastructure:

11. eSTAR: *eScience Telescopes for Astronomical Research*
    http://www.estar.org.uk
12. RoboNet: *RoboNet-1.0*
    http://www.astro.livjm.ac.uk/RoboNet
13. RAPTOR: *RAPid Telescopes for Optical Response*

http://www.raptor.lanl.gov, and
http://www.thinkingtelescopes.lanl.gov (*Thinking Telescopes Project*)
http://www.thinkingtelescopes.lanl.gov/Communication.htm (*TALONS*)

14. ROBOT: *A list of robotic telescope projects*
    http://www.astro.physik.uni-goettingen.de/~hessman/MONET/links.html
15. 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:

16. ID: *IVOA Identifiers*
    http://www.ivoa.net/Documents/latest/IDs.html
17. RM: *Resource Metadata for the Virtual Observatory*
    http://www.ivoa.net/Documents/latest/RM.html
18. STC: *Space-Time Coordinates Metadata for the Virtual Observatory*
    http://www.ivoa.net/Documents/latest/STC.html
19. UCD: *Unified Content Descriptor*
    http://www.ivoa.net/Documents/latest/UCD.html, or
    http://cdsweb.u-strasbg.fr/UCD
20. VOConcepts: *a proposed UCD for Astronomical Objects, Events, and Processes*
    http://monet.uni-sw.gwdg.de/twiki/bin/view/VOEvent/UnifiedContentDescriptors
21. VOTable: *Format Definition*
    http://www.ivoa.net/Documents/latest/VOT.html

Astronomical resources:

22. NED: *NASA/IPAC Extragalactic Database*
    http://nedwww.ipac.caltech.edu/
23. SIMBAD: *Set of Identifications, Measurements and Bibliography for Astronomical Data*
    http://simbad.u-strasbg.fr/Simbad
24. TYCHO: *De Stella Nova*
    http://www.texts.dnlb.dk/DeNovaStella/Index.html (in Danish)
25. UNITS: *Standards for Astronomical Catalogues: Units*
    http://vizier.u-strasbg.fr/doc/catstd-3.2.htx
26. UTC: *the future of Coordinated Universal Time*
    http://www.ucolick.org/~sla/leapsecs

Computing resources:

27. Checksum: *FITS Checksum Proposal*
    http://heasarc.gsfc.nasa.gov/docs/heasarc/fits/checksum23may02
28. ISO 8601: *standard representation of dates and times*
    http://www.cl.cam.ac.uk/~mgk25/iso-time.html
29. PGP: *Pretty Good Privacy*
    http://www.pgpi.org
30. SAML: *Security Assertion Markup Language*
    http://www.opensaml.org
31. S-HTTP: *Secure HyperText Transfer Protocol*
    http://www.faqs.org/rfcs/rfc2660.html
32. SSL: *Secure Sockets Layer*
    http://www.openssl.org
33. XML: *Extensible Markup Language*
    http://xml.coverpages.org/xml.html, and
    http://xml.coverpages.org/schemas.html, or

http://www.ucc.ie/xml (FAQ)
34. X.509: *Public Key Certificate Infrastructure*
http://www.faqs.org/rfcs/rfc3280.html

Appendix: Existing event systems

Several systems already exist for notification of immediate astrophysical effects. The earliest is the Central Bureau for Astronomical Telegrams [2] of the International Astronomical Union (IAU); another is the Gamma-ray Burst Coordinate Network [3] that is associated with satellites that detect GRBs. The Astronomer's Telegram [1] system is more general, and has been successful for a number of years; the RealTime Virtual Observatory (RTVO) [4] 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) [15], 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) [2], 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 (GRB) Coordinate Network

The GCN system [3] 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) [1] 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) [15] 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

The new rtVO system [4] 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.
