Sky Event Reporting Metadata (*VOEvent*)
Version 1.1

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Abstract

VOEvent [21] 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. 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, repositories, publishers or brokers; 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, for instance, RoboNet-1.0 [13] and eStar[3] in the United Kingdom, and VOEventNet[6] in the USA. 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 [9], Pan-STARRS [10] and LSST [8], satellites like Swift [12], and more singular experiments like LIGO [7]. RAPTOR [11] at the Los Alamos National Laboratory is another such project that is already operating with prototype support for VOEvent. In short, the community has demonstrated that robotic telescopes [14] can quickly follow-up events using the standard outlined in this document. 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) [4] 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 "brokers" — which will subscribe to VOEvent-producing systems and provide filter services to client groups ("subscribers") 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 [30] 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.

2. Usage

This document defines the semantics of an alert packet known as VOEvent [21]. 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 through a citation mechanism. 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 Publishing VOEvent Packets

VOEvent packets express published sky transient alerts. VOEvent users subscribe to the types of alerts pertinent to their science goals. In addition to Publisher and Subscriber, the following roles define the interchange of VOEvent semantics:

- An ***Author*** is anyone (or any organization) creating scientific content suitable for representation as a sky transient alert. An author will typically register with the IVOA registry, so that the **<Who>** element of VOEvent packets can be small and reusable, expressing only the IVOA identifier needed to retrieve the contact information for the author.

- A ***Publisher*** receives alerts from one-or-more authors, and assigns a unique identifier to each resulting packet. Either the author or the publisher generates the actual XML syntax of the event, but the publisher is responsible for the validity of the packet relative to the VOEvent schema. Publishers will register with the IVOA registry as described below.

- A ***Repository*** subscribes to one or more VOEvent streams, persists packets either permanently or temporarily, and runs a service that allows clients to resolve identifiers and apply complex queries to its holdings. A given packet had one Publisher but may be held in more than one Repository. Public repositories will register with the IVOA registry.

- A ***Subscriber*** is any entity that receives VOEvent packets for whatever purpose. Subscribers can find out how to get certain types of events by consulting the lists of publishers and repositories in the IVOA registry. A subscription is a filter on the stream of events from a publisher: the subscriber is notified whenever certain criteria are met. For example, the filter may involve the curation part of the event (*e.g.*, *"all events published by the Swift spacecraft"*), its location (*"anything in M31"*), or it may reference the detailed metadata of the event itself (*"whenever the cosmic ray energy is greater than 3 TeV"*).

- A ***Broker*** or ***Relay***, also sometimes known as a *Filter*, is any combination of the atomic roles of Publisher, Repository, or Subscriber that also offers arbitrary application-level functionality. See the IVOA VOEvent Transport Note [21] for further discussion.

2.2 VO Identifiers (IVORNs) and Publishers

VOEvent benefits from the IVOA identifiers developed for the VO registry. Such an identifier is called an *IVORN*, that is, an *International Virtual Observatory Resource Name*. It is required to begin with ***"ivo://"***, and will stand in for a particular packet. 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. VOEvent 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. For these reasons, VOEvent packets will often contain VO identifiers [16]. These take the general form ***ivo://authorityID/resourceKey#local_ID***, and are references to metadata packets that may be found at a VO registry or VOEvent repository. There are several types of metadata schema that the registry can hold. For the purposes of VOEvent, the principal schemata are:

- **VOEvent**: the metadata packet for an alert resulting from the observation of a transient celestial event. This schema is defined in this document.

- **VOEvent Publisher**: the metadata packet for a publisher of VOEvents, including information about who is running it, what kinds of events are published, and information about how to subscribe to the feed of published events.

- **VOEvent Repository**: the metadata packet to describe a repository of VOEvents, including the list of publishers whose events are kept, the service endpoint to query the repository, the endpoint to resolve a VOEvent identifier.

- **Author Organization**: this metadata describes an author, including contact information and a description of the project. The VOEvent **<Who>** element contains either a reference to an author's

IVORN or explicit contact information sufficient to describe the author.

When such an identifier is *resolved*, it means that the VOEvent metadata packet is obtained in exchange for the identifier. Such resolution happens through the global, distributed IVOA registry in stages. The registry is queried to locate a repository holding the relevant packet, and then the repository is queried for the packet itself. The part of the IVORN before the "#" symbol points to the publisher of the event; the whole IVORN (that includes the local_ID) points to the event. Thus VOEvent identifiers are overloaded; they contain a publisher identifier, then the "#" sign, then the local reference.

This is a key point in understanding VOEvent identifiers: **The Event identifier also expresses the Publisher identifier.** For example:

- *ivo://nvo.caltech/VOEventPublisher#60601*

  This identifier points to a specific VOEvent (number 60601) that was published by the Caltech publisher. However, this ID will not resolve from the global VO registry, but only from a repository that has the Caltech-published events.

- *ivo://nvo.caltech/VOEventPublisher*

  The Publisher identifier can be looked up in any VO registry, returning a description of the Publisher, such as who runs it, how many events it has published, how to subscribe, etc. However, for resolving the identifier, we want a repository, so a different registry query would be used: *"Find repositories that keep the events published by this publisher"*

The scheme outlined here is analogous to ISBN identifiers for books (International Standard Book Number). An ISBN example is 1-55860-253-4. The first part, 1-55860, identifies the publisher and the second part, 253, is a title identifier local to that publisher. There is also a check digit, 4, which is a feature a VOEvent Publisher might also choose to utilize.

The nature of a standard service to query VOEvent repositories and the metadata necessary to describe a repository within the VO registry remain under debate in the VOEvent Working Group.

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/spam associated with this communications channel. All of the familiar internet security worries apply to VOEvents. These questions are addressed elsewhere.

2.4 VOEvent Transport

VOEvent [21] is a semantic specification for describing the content and meaning of astronomical transient alert messages. It is anticipated that VOEvent messages will be delivered using a variety of transport protocols, but the VOEvent Working Group has designated a single common reference protocol [21] to serve to commission the emerging VOEvent network and new brokers within that network. Further discussion of transport is outside the scope of this document.

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 [6] 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 at most one of each of the following optional sub-elements:

<Who>	*Author Identification*
<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 ***ivorn*** 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. The intent of VOEvent is to describe a single astronomical transient event per packet. Multiple events should be expressed using multiple packets. On the other hand, complex observations may best be expressed using multiple follow-up packets or via embedded **<References>** to external resources such as VOTables or RTML documents. XML structures other than those listed in this document should be used with care within a **<VOEvent>** element, but some applications may require the freedom to reference schema outside the scope of this specification. 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 *ivorn* — Each VOEvent packet is required to have one-and-only-one identifier, expressed with the ***ivorn*** 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 IVORNs from a variety of useful and appropriate namespaces. The identifier actually contains TWO IDENTIFIERS: the first part is the identifier for the publisher, and the event identifier is built from this, then a # symbol, then a local string that is meaningful only in the context of that publisher.

3.1.2 *role* — The optional ***role*** attribute accepts several possible values, including these:

- 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.
- The value *"utility"* means that the packet expresses nothing about astrophysics, but rather information about the observing system. This could be used, for example, for a satellite to express that it has changed its configuration.
- 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 "1.1" 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 [25] might start:

```
<VOEvent ivorn="ivo://uraniborg.hven#1572-11-11/0001"
      role="observation" version="1.1" 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].

Typical curation content would include:

3.2.1<Author>

Author information follows the IVOA curation information schema: the organization responsible for the packet can have a title, short name or acronym, and a logo. A contact person has a name, email, and phone number. Other contributors can also be noted.

An example of Author information might be:

```
<Author>
    <title>Rapid Telescope for Optical Response</title>
    <shortName>Raptor</shortName>
    <logoURL>http://www.raptor.lanl.gov/images/RAPTOR_patchLarge.jpg</logoURL>
```

```
        <contactName>Robert White</contactName>
        <contactEmail>rwhite@lanl.gov</contactEmail>
        <contactPhone>+1 800 555 1212</contactPhone>
    </Author>
```

3.2.2<AuthorIVORN>

As an alternative to quoting Author information over and over, this inofrmation can be published to the VO registry, then referenced through an IVORN. The **<AuthorIVORN>** element contains the identifier of the organization 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, **<AuthorIVORN>** 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.

3.2.3 <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 [29]). 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 [27].

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

```
<Who>
    <AuthorIVORN>ivo://uraniborg.hven/Tycho</AuthorIVORN>
    <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 or causes.

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 §4.1 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. 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 [22]; however, a **<Param>** must be expressed as an empty element and 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 [22] which relies on [26].

3.3.1.4 ***ucd*** — A UCD [19] expression characterizing the nature of the **<Param>**.

For example, here are three values from a GCN [4] notice:

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

In VOEvent, these can be represented as:

```
<Param name="TRIGGER_NUM" value="114299" ucd="meta.id" />
<Param name="RATE_SIGNIF" value="20.49"  ucd="stat.snr" />
<Param name="GRB_INTEN  " value="73288"  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" ucd="phot.count" />
    <Param name="peak" value="1310"  ucd="arith.rate;phot.count" />
</Group>
```

Note that the UCDs above carry the semantics of photon 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="mag"   ucd="phot.ma;em.opt.R" value="13.2" />
        <Param name="epoch" ucd="time.epoch" value="245523.12345 />
    </Group>
    <Group type="phot_pt">
        <Param name="mag"   ucd="phot.mag;em.opt.R" value="13.4" />
        <Param name="epoch" ucd="time.epoch" value="245523.46533" />
    </Group>
    <Group type="phot_pt">
        <Param name="mag"   ucd="phot.mag;em.opt.R" value="13.0" />
        <Param name="epoch" ucd="time.epoch" value="245523.76444" />
    </Group>
</What>
```

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

A VOEvent packet will typically include information about where in the sky and when in time an event was detected, and from what location, along with spatial and temporal coordinate systems and errors. If either the spatial or temporal locators are absent, it is to be assumed that the information is either unknown or irrelevant. VOEvent v1.1 requires the IVOA Space-Time Coordinate (STC) specification version 1.30 or later; the **<WhereWhen>** element may reference an arbitrary number of STC [18] **<ObsDataLocation>** elements. VOEvent publishers should construct expressions that concisely provide all information that is scientifically significant to the event, and no more than that. See §4.1 for an example of usage.

STC expressions are used to locate the physical phenomena associated with a VOEvent alert in both time and space as described below. The **<ObsDataLocation>** element is a combination of information describing the location of an observation in the sky along with information describing the location of the observatory from which that observation was made. Both the sky and the observatory are in constant motion, and STC inextricably relates spatial and temporal information.

The ***xmlns*** attribute points to an XML namespace declaration, so that contained elements reference the STC schema rather than the VOEvent schema. It is anticipated that VOEvent Brokers may choose to mirror the STC schema (and any future dependent schemata) for the benefit of their Subscribers.

```
<WhereWhen>
    <ObsDataLocation xmlns="http://www.ivoa.net/xml/STC/stc-v1.30.xsd">
        <ObservatoryLocation/>
        <ObservationLocation/>
    </ObsDataLocation>
</WhereWhen>
```

3.4.1 ObservationLocation

The **<ObservationLocation>** should contain a link to a coordinate system, **<AstroCoordSystem>**, as well as the actual coordinates, **<AstroCoords>**, containing a reference back to the coordinate system specification. For example:

```
<ObservationLocation>
```

```
        <AstroCoordSystem id="UTC-FK5-GEO" xlink:type="simple"
            xlink:href="ivo://STClib/CoordSys#UTC-FK5-GEO"/>

        <AstroCoords coord_system_id="UTC-FK5-GEO">
            <Time unit="s">
                <TimeInstant>
                    <ISOTime>2004-07-15T08:23:56</ISOTime>
                </TimeInstant>
                <Error>2</Error>
            </Time>
            <Position2D unit="deg">
                <Value2>
                    <C1>148.88821</C1>
                    <C2>69.06529</C2>
                </Value2>
                <Error2Radius>0.03</Error2Radius>
            </Position2D>
        </AstroCoords>
    </ObservationLocation>
```

Specifying errors is optional but recommended for both time and space components.

The **<AstroCoords>** element is tied by its ***coord_system_id*** attribute to an **<AstroCoordSystem>** that has been tagged by an identical ***id*** attribute, and that points to a coordinate system definition in a library through the ***xlink:href*** attribute. That library contains the full description of the coordinate system. The ***coord_system_id*** needs to be identical to ***id***, and any arbitrary string literal would be technically acceptable. By convention, however, this string is specified identically to the last part of the ***xlink:href***. For instance, the same value, *UTC-FK5-GEO*, is repeated in three successive lines of the code fragment above. This triply repeated string is the key to understanding the context of the coordinates.

A ***coord_system_id*** is built from a time part, a space part, and a "center" specification, concatenated in that order and separated by hyphens. Astronomical coordinate systems are extremely varied, but all VOEvent subscribers should be prepared to handle coordinates expressed as combinations of these basic defaults:

- The time part can be *UTC* (Coordinated Universal Time [27]), *TT* (Terrestrial Time, currently 65.184 seconds ahead of UTC), or *TDB* (Barycentric Dynamical Time).
- The space part can be equatorial coordinates (right ascension and declination) expressed in either the *ICRS* or *FK5* coordinate systems.
- The center specification can be *TOPO* (*i.e.*, the location of the observatory), *GEO* (geocentric coordinates), or *BARY* (relative to the barycenter of the solar system).

It is assumed that the center reference position (origin) is the same for both space and time coordinates. That means, for instance, that *BARY* should only be paired with *TDB* (and vice-versa). See the STC specification [18] for further discussion. The list of **<AstroCoordSystem>** defaults that VOEvent brokers and clients may be called upon to understand is:

- *TT-ICRS-TOPO*
- *UTC-ICRS-TOPO*
- *TT-FK5-TOPO*
- *UTC-FK5-TOPO*

- *TT-ICRS-GEO*
- *UTC-ICRS-GEO*
- *TT-FK5-GEO*
- *UTC-FK5-GEO*

- *TDB-ICRS-BARY*
- *TDB-FK5-BARY*

The STC specification, in particular **<ObsDataLocation>** and its contained elements, allows more exotic coordinate systems (for example, describing planetary surfaces). Further description of how VOEvent packets might be constructed to convey such information to subscribers is outside the scope of this document. As with other elements of an alert packet, subscribers must be prepared to understand coordinates expressing the science and experimental design pertinent to the particular classes of sky transients that are of interest.

In short, subscribers are responsible for choosing what VOEvent packets and thus ***coord_system_id*** values they will accept. Further, subscribers may choose not to distinguish between coordinate systems that are only subtly different for their purposes — for instance between *ICRS* or *FK5*, or between *TOPO* or *GEO*. As software determines whether a packet's ***coord_system_id*** describes a supported coordinate system, the question is also what accuracy is required and what coordinate transformations may be implicitly or explicitly performed to that level of accuracy.

A similar question faces the authors of VOEvent packets, who must make a judicious choice between the available coordinate system options to meet the expected scientific needs of consumers of those packets. If a detailed or high accuracy coordinate system selection is not needed, ***UTC-ICRS-TOPO*** would be a good choice as an interoperability standard.

3.4.2 ObservatoryLocation

The **<ObservatoryLocation>** element is used to express the location from which the observation being described was made. It is a required element for expressing topocentric coordinate systems. An instance of **<ObservatoryLocation>** may take two forms. In the first, an observatory location may be taken from a library, for example:

```
<ObservatoryLocation id="Palomar" xlink:type="simple"
    xlink:href="ivo://STClib/Observatories#Palomar" />
```

The name of the id attribute is in *red italics*, and should be same as the portion of the link after the "#" symbol, in this case "Palomar" (also in *red italics*). It may have a value indicating a specific registered observatory, such as: KECK, KPNO, JCMT, MMTO, VLA, *etc.* , or it may indicate one of the following generic observatory locations:

- *GEOSURFACE* - any location on the surface of the earth
- *GEOLEO* - any location in Low Earth Orbit (altitude<700 km)
- *GEOGSO* - any location within Geostationary orbit altitude
- *GEONBH* - any location within 50,000 km of the geocenter
- *GEOLUN* - any location within the Moon's orbit

For example, a packet might contain the following **<ObservatoryLocation>** to indicate that the coordinates expressed in the **<WhereWhen>** element are located with an accuracy comprising the Earth's surface:

```
<ObservatoryLocation id="GEOSURFACE" xlink:type="simple"
    xlink:href="ivo://STClib/Observatories#GEOSURFACE" />
```

VOEvent Brokers are designed to comprise a high reliability, low latency, network. These qualities can be used, as with mirroring the STC schema, to provide robust access for VOEvent Subscribers by serving the library of observatory information.

The second option for **<ObservatoryLocation>** is that an observatory can be located by specifying the actual coordinate values of longitude, latitude and altitude on the surface of the Earth:

```
<ObservatoryLocation id="KPNO">

    <AstroCoordSystem id="UTC-GEOD-TOPO" xlink:type="simple"
        xlink:href="ivo://STClib/CoordSys#UTC-GEOD-TOPO"/>

    <AstroCoords coord_system_id="UTC-GEOD-TOPO">
        <Position3D>
            <Value3>
                <C1 pos_unit="deg">248.4056</C1>
                <C2 pos_unit="deg">31.9586</C2>
                <C3 pos_unit="m">2158</C3>
            </Value3>
        </Position3D>
    </AstroCoords>
</ObservatoryLocation>
```

3.4.3 Parsing the WhereWhen Element

When parsing a VOEvent packet, the following pseudocode may be of use to provide the time, the right ascension and the declination, if the author used *ICRS* spatial coordinates and *UTC* time.

```
Let  x =/voe:VOEvent/WhereWhen/ObsDataLocation/ObservationLocation/AstroCoords
If x[@coord_system_id='UTC-ICRS-TOPO'] then
   Let Time = x/Time/TimeInstant/ISOTime
   Let RA = x/Position2D/Value2/C1
   Let Dec = x/Position2D/Value2/C2
```

The coordinate system is first checked to verify that it is set to a specific value(s), *UTC-ICRS-TOPO*. In practice, a subscriber may not care about the difference between *ICRS* and *FK5* (of the order of 0.01") or between *TOPO* and *GEO* (in terms of timing, this is of the order of 25 ms for ground-based and low-earth-orbit observatories). Software may be written to simply accept anything that contains *ICRS* or *FK5*, *TOPO* or *GEO*.

3.4.4 Solar Events

The following coordinate systems are recognized for solar event data:

- *UTC-HPC-TOPO* - Cartesian helio-projective coordinates (solar disk)
- *UTC-HPR-TOPO* - Polar helio-projective coordinates (coronal events)
- *UTC-HGS-TOPO* - Stonyhurst heliographic coordinates
- *UTC-HGC-TOPO* - Carrington heliographic coordinates

What this means is that these coordinate combinations will be supported in the library and that, hence, use of VOEvent by the solar research community is supported. It does not imply, of course, that all VOEvent participants are expected to recognize and handle these solar coordinates - nor, for that matter, that solar subscribers be able to handle equatorial coordinates.

3.4.5 Events Observed from Spacecraft

Transient event alerts resulting from observations made on distant spacecraft may reference coordinates that require correction for ground-based follow-up. The precise definition of "distant" will depend on the objects observed, the instrumentation and the science program. For remote objects such as gamma-ray bursts or supernovae, it is likely that spatial coordinates measured from spacecraft in Earth orbit will be immediately useful — indeed, the error box of the reported coordinates may be much larger than than the pointing accuracy of the follow-up telescope. On the other hand, the field of view of the instrument on that telescope may be many times larger than the error box. Subscribers must always balance such concerns — this is just one facet of matching "scientific impedance" between discovery and follow-up observations.

Even if the spatial targeting coordinates require no correction, the light travel time may be quite significant between a spacecraft and any follow-up telescopes on the Earth. Subscribers may need to adjust wavefront arrival times to suit.

Authors of such events may choose to handle reporting the location of the spacecraft in different ways. First, they may simply construct the complex **<ObservatoryLocation>** element that correctly represents the rapidly moving location of an orbiting observatory. Further discussion of this topic is outside the scope of the present document, see the STC specification [18]. Of course, any subscribers to such an event stream would have to understand such an **<ObservatoryLocation>** in detail and be able to calculate appropriate time-varying adjustments to the coordinates in support of their particular science program.

Alternately, an author of event alert packets resulting from spacecraft observations might simply choose to correct their observations themselves into geocentric or barycentric coordinates. Finally, for spacecraft in Earth orbit, authors might choose to report an **<ObservatoryLocation>** such as *GEOLUN*, indicating a rough position precise to the width of the Moon's orbit. These two options might be combined by both making a geocentric correction — for instance, to simplify the handling of timing information — with the reporting of a *GEOLEO* location, for example.

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 urgency or time-criticality of the VOEvent, expressed as an ISO-8601 [29] 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 to attach the name of some specific astronomical object or feature. These may be organized using the **<Inference>** element, which permits expressing the nature of the ***relation*** of the contained elements to the event in question as well as an estimate of its likelihood via its ***probability*** attribute.

3.6.3 <Concept> — classification

The value of a **<Concept>** element uses a controlled vocabulary to express the hypothesized astrophysics. This standard VO ontology or formal UCD-like vocabulary of astronomical concepts vocabulary is still in development (see [19] and [20], for example).

3.6.4<Description> — natural language

This element provides a natural language description of the concept, either as a replaement for the <Concept> element, or as an elaboration.

3.6.5<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 [23] or SIMBAD [24].

3.6.6<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***:

3.6.6.1 ***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.

3.6.6.2 ***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. Typical values might be "associated" - a SN is associated with a particular galaxy - or "identified" - a SN is identified as corresponding to a particular precursor star. Such a one-to-one identification is considered to be the default ***relation*** in the absence of the attribute.

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="1574-05-11T12:00:00">
    <Inference probability="1.0">
        <Name>Tycho's Stella Nova</Name>
        <Concept>stars.supernova.Ia</Concept>
    </Inference>
    <Inference probability="1.0" relation="associated">
        <Name>3C 10</Name>
        <Concept>ISM.SNRemnant</Concept>
        <Description>Supernova remnant</Description>
    </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 **<EventIVORN>** elements. The standard does not attempt to enforce references to be logically consistent; this is the responsibility of publishers and subscribers.

3.7.1 <EventIVORN> — references and cites

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

An **<EventIVORN>** 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 **<EventIVORN>** 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 — subscribers 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>
    <EventIVORN cite="retraction">ivo://uraniborg.hven#572-11-11/0001</EventIVORN>
    <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>**. Users may wish to embellish Description sections with HTML tags such as images and URL links, and these should not be seen by the XML parser, as they will cause the VOEvent XML to be invalid against the schema. HOWEVER, it is possible to use the CDATA mechanism of XML to quote text at length, so this may be used for complicated tagged Descriptions. See example in section 4 for usage.

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, with attributes only.

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 and instrumental configurations — to list only a few. This content will be expressed in various graphics and image formats such as FITS, as VOTables [22], 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 — *"ivorn"*, to refer to IVO resources. The default value is *"url"*.

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

A **<Reference>** used to provide general purpose ancillary data:

```
<Group type="MyFilterWithImage">
    <Param name"=filter" value="H">
    <Reference uri="http://.../h.fits" />
</Group>
```

An example of the indirection of a VOEvent packet using **<Reference>** (also see §4.2):

```
<VOEvent ivorn="ivo://raptor.lanl#235649409/sn2005k" role="observation" version="1.1">
    <Reference uri="http://www.raptor.lanl.gov/documents/event233.xml" />
</VOEvent>
```

4: VOEvent Examples

4.1 A typical VOEvent packet

The author is RAPTOR [11], and the publisher is Caltech. 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.

```
<?xml version="1.0" encoding="UTF-8"?>
<voe:VOEvent
    ivorn="ivo://raptor.lanl/VOEvent#235649409"
    role="observation"
    version="1.1"
    xmlns:voe="http://www.ivoa.net/xml/VOEvent/v1.1"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="http://www.ivoa.net/xml/VOEvent/v1.1
    http://www.ivoa.net/xml/VOEvent/VOEvent-v1.1.xsd">

    <Citations>
        <EventIVORN cite="followup">ivo://raptor.lanl/VOEvent#235649408</EventIVORN>
        <Description>This is an observation of the earlier event but with
            improved square-galaxy discrimination</Description>
    </Citations>

    <Who>
        <AuthorIVORN>ivo://raptor.lanl/organization</AuthorIVORN>
        <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"/>
        <Reference uri="http://raptor.lanl.gov/data/lightcurves/235649409"/>
        <Description>This is the light curve associated with the observation.</Description
    </What>

    <WhereWhen>
        <ObsDataLocation xmlns="http://www.ivoa.net/xml/STC/stc-v1.30.xsd"
            xmlns:xlink="http://www.w3.org/1999/xlink">

            <ObservatoryLocation id="KPNO" xlink:type="simple"
                xlink:href="ivo://STClib/Observatories#KPNO"/>
```

```
                <ObservationLocation>
                    <AstroCoordSystem id="UTC-ICRS-TOPO" xlink:type="simple"
                        xlink:href="ivo://STClib/CoordSys#UTC-ICRS-TOPO"/>
                    <AstroCoords coord_system_id="UTC-ICRS-TOPO">
                        <Time unit="s">
                            <TimeInstant>
                                <ISOTime>2005-04-15T23:59:59</ISOTime>
                            </TimeInstant>
                            <Error>1.0</Error>
                        </Time>
                        <Position2D unit="deg">
                            <Value2>
                                <C1>148.88821</C1>
                                <C2>69.06529</C2>
                            </Value2>
                            <Error2Radius>0.03</Error2Radius>
                        </Position2D>
                    </AstroCoords>
                </ObservationLocation>
            </ObsDataLocation>
        </WhereWhen>

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

        <Why importance="0.8" expires="2005-04-16T02:34:16">
            <Concept>process.variation.burst;em.opt</Concept>
            <Description>Fast Orphan Optical Transient. Don't know what caused it,
                but looks like we found the host galaxy</Description>
            <Inference relation="associated" probability="0.9">
                <Name>NGC1234</Name>
            </Inference>
        </Why>
    </voe:VOEvent>
```

4.2 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 ***ivorn*** is set to the ***ivorn*** of the original packet, allowing an intervening client such as an aggregator to persist the ***ivorn*** 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"?>
<voe:VOEvent
    ivorn="ivo://raptor.lanl/VOEvent#23564"
    role="observation"
    version="1.1"
    xmlns:voe="http://www.ivoa.net/xml/VOEvent/v1.1"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="http://www.ivoa.net/xml/VOEvent/v1.1
    http://www.ivoa.net/xml/VOEvent/VOEvent-v1.1.xsd">

    <Reference uri="http://raptor.lanl.gov/VOEventRepository/23564"/>
```

```
</voe: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. eSTAR: *eScience Telescopes for Astronomical Research*
   http://www.estar.org.uk
4. GCN: *The Gamma-Ray Burst Coordinates Network*
   http://gcn.gsfc.nasa.gov
5. rtVO: *The real-time Virtual Observatory*
   http://www.rtvo.net
6. VOEventNet: *US-VO Event network*
   http://voeventnet.caltech.edu/

Some surveys reporting events (or planning to):

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

Robotic telescope infrastructure:

13. RoboNet: *RoboNet-1.0*
    http://www.astro.livjm.ac.uk/RoboNet
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. VOEvent: *Sky Event Reporting Metadata*
    http://www.ivoa.net/Documents/latest/VOEvent.html
    http://www.ivoa.net/xml/VOEvent/VOEvent-v1.1.xsd (schema)
    http://www.ivoa.net/Documents/latest/VOEvent_transport.html (transport)
    http://www.ivoa.net/twiki/bin/view/IVOA/IvoaVOEvent (working group)
22. VOTable: *Format Definition*
    http://www.ivoa.net/Documents/latest/VOT.html

Astronomical resources:

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

Computing resources:

28. Checksum: *FITS Checksum Proposal*
    http://heasarc.gsfc.nasa.gov/docs/heasarc/fits/checksum23may02
29. ISO 8601: *standard representation of dates and times*
    http://www.cl.cam.ac.uk/~mgk25/iso-time.html
30. XML: *Extensible Markup Language*
    http://xml.coverpages.org/xml.html, and
    http://xml.coverpages.org/schemas.html, or
    http://www.ucc.ie/xml (FAQ)
