

# The CHIME/FRB VOEvent Service

## Real-time Alerts of CHIME Fast Radio Bursts

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# Outline

- ▶ Overview
- ▶ Subscriptions and event handling
- ▶ Real-time alerts
- ▶ Thresholds, data quality, and performance
- ▶ Post real-time alerts
- ▶ Conclusion

# Overview

# A Push Service

The Service is **push-based**: alerts are delivered to subscribers only once.

Contrast with **pull-based**: alerts cannot be requested from the Service.

Subscribers must plan their follow-up campaigns to be able to **take action at any given moment** while the Service is live.

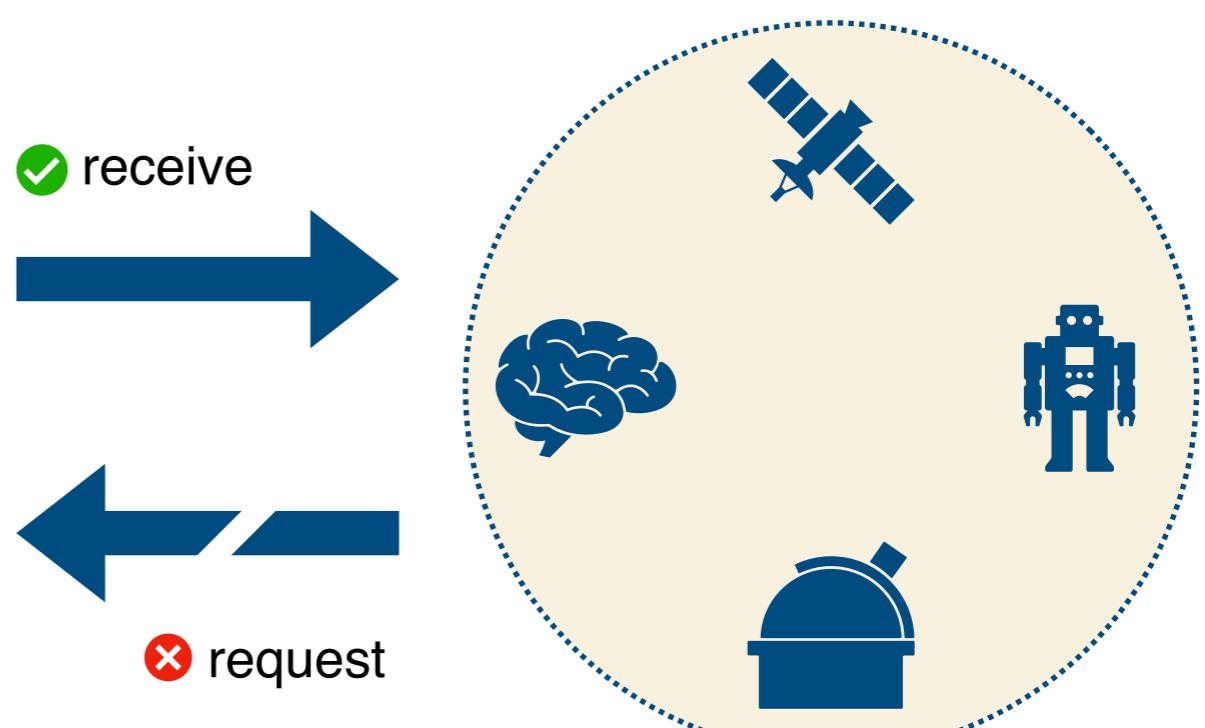
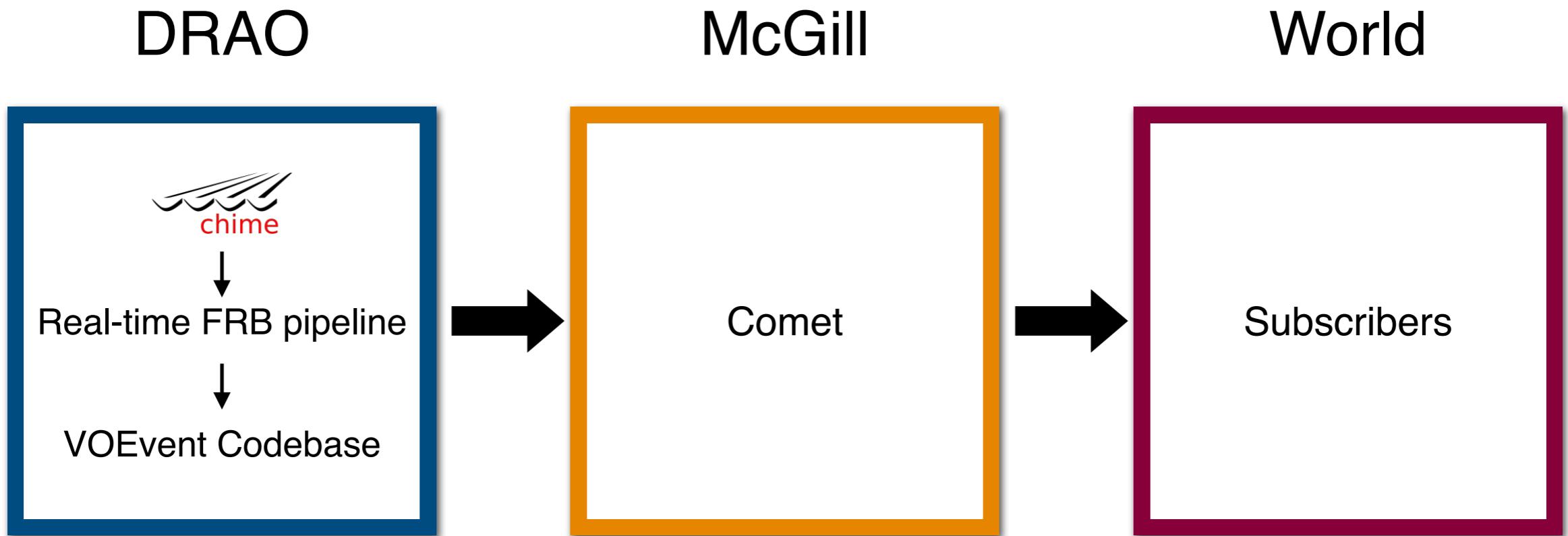


Photo credit: CHIME Collaboration

# The CHIME/FRB VOEvent Service



# The CHIME/FRB VOEvent Service



# Subscriptions and Alert Handling

# How to Subscribe to the Service

The Service is operated on a subscription basis and all new subscribers must submit basic information to facilitate delivery of VOEvents.

CHIME/FRB will collect user information and store it in a password-protected database located at the CHIME telescope site.

**No passwords will be required or collected from the subscriber.**

# How to Subscribe to the Service

## Items that will be Stored by CHIME/FRB

Subscription requests can be made on the CHIME/FRB public webpage [here](#).

### 1. Email address

- ▶ Email formatted VOEvents may be sent here.
- ▶ Changes, interruptions, or other important communications about the service will be sent here.
- ▶ Be sure to **check junk/spam folders** frequently to avoid missing important communications from the Service.

# How to Subscribe to the Service

## **Items that will be Stored by CHIME/FRB**

Subscription requests can be made on the CHIME/FRB public webpage [here](#).

### 2. Name

- ▶ Subscriber's name.
- ▶ This individual will be addressed in all email communications about the Service.

# How to Subscribe to the Service

## **Items that will be Stored by CHIME/FRB**

Subscription requests can be made on the CHIME/FRB public webpage [here](#).

### 3. Institution or affiliation

- ▶ The name of the scientific collaboration to which the subscriber belongs; or,
- ▶ The name of the academic institution with which the subscriber is associated; or,
- ▶ Another recognized collaboration, experimental group, or research body.

# How to Subscribe to the Service

## Items that will be Stored by CHIME/FRB

Subscription requests can be made on the CHIME/FRB public webpage [here](#).

### 4. IP address of a VOEvent broker

- ▶ The **public** IP address where the subscriber's VOEvent broker will run.
- ▶ Only required if subscriber elects to receive XMLs.
- ▶ Use a **static** IP address wherever possible.
- ▶ Public IP addresses can be obtained with search engines and at the command line.

```
$ dig +short myip.opendns.com @resolver1.opendns.com
```

```
$ dig TXT +short o-o.myaddr.l.google.com @ns1.google.com
```

# How to Subscribe to the Service

## Items that will be Stored by CHIME/FRB

Subscription requests can be made on the CHIME/FRB public webpage [here](#).

### 5. Flag to receive XML version

- ▶ Answer **yes** to receive the VOEvent XML. It will be delivered to the VOEvent broker with the IP address as specified previously.
- ▶ Answer **no** to abstain from receiving the XML version of the VOEvent.

# How to Subscribe to the Service

## Items that will be Stored by CHIME/FRB

Subscription requests can be made on the CHIME/FRB public webpage [here](#).

### 6. Flag to receive email version

- ▶ Answer **yes** to receive an email formatted version of the VOEvent at the email address that was provided in part 1.
- ▶ Answer **no** to abstain from receiving email VOEvents.

# How to Receive CHIME/FRB VOEvents

## Getting the machine-readable VOEvent XML

### Step 1

Subscription requests can be made on the CHIME/FRB public webpage [here](#).

### Step 2

Install a VOEvent broker. **The remaining material assumes use of [comet](#).**

### Step 3

Assuming the IP address of the broker has been added to the allow-list, run the broker with the following command:

```
$ twistd -n comet --remote=chimefrb.physics.mcgill.ca
--local-ivo=ivo://test_user/test -print-event
```

# How to Receive CHIME/FRB VOEvents

## Getting the email version of the VOEvent

### Step 1

Subscription requests can be made on the CHIME/FRB public webpage [here](#).

### Step 2

Emails are sent to the address provided during the subscription process.

### Notes

- (1) **Monitor spam and junk** folders for messages from [vo.event.sender@gmail.com](mailto:vo.event.sender@gmail.com), the dedicated CHIME/FRB VOEvent email agent.
- (2) **Do not reply** to emails from [vo.event.sender@gmail.com](mailto:vo.event.sender@gmail.com).
- (3) Expect communications about the Service from the above address to be delivered to the email address you provided in the subscription form.

# How to Parse CHIME/FRB VOEvents

## Parsing the machine-readable VOEvent XML

### Step 1

Become familiar with comet event handlers (documented [here](#)).

### Step 2

Use an XML convenience library for extracting VOEvent meta data ([voevent-parse](#)).

### Step 3

Obtain core CHIME/FRB meta data using a convenience function e.g.

[`voeventparse.get\_grouped\_params\(\)`](#)

### Step 4

Select meta data of interest from the above e.g. DM, SNR, sky location.

# How to Parse CHIME/FRB VOEvents

**In need of further instruction?**

Follow our Jupyter notebook tutorial!

Step 1

Go to the CHIME/FRB Open Data GitHub IO [page](#).

Step 2

Review the Jupyter notebook tutorial.

Step 3

If desired, one can download the Jupyter [notebook](#) and associated XML [files](#).

# Real-time Alerts

# Virtual Observatory Events (VOEvents)

The VOEvent XML Standard is described by the IVOA [here](#).

## Key Features

- ▶ Machine readable representation of meta data, especially objects.
- ▶ Relies on XML, an existing object representation medium for web services.
- ▶ Standardizes reports of observations for virtually any domain.

## Use Cases

- ▶ Gamma-ray Coordinates Network or Transient Alert Network ([GCN/TAN](#)) brings together instruments across the electromagnetic spectrum as they coordinate multi-wavelength observations of gamma-ray or X-ray targets with VOEvents.

# FRB VOEvents

The FRB VOEvent standard was first defined in [Petroff et al. 2017](#).

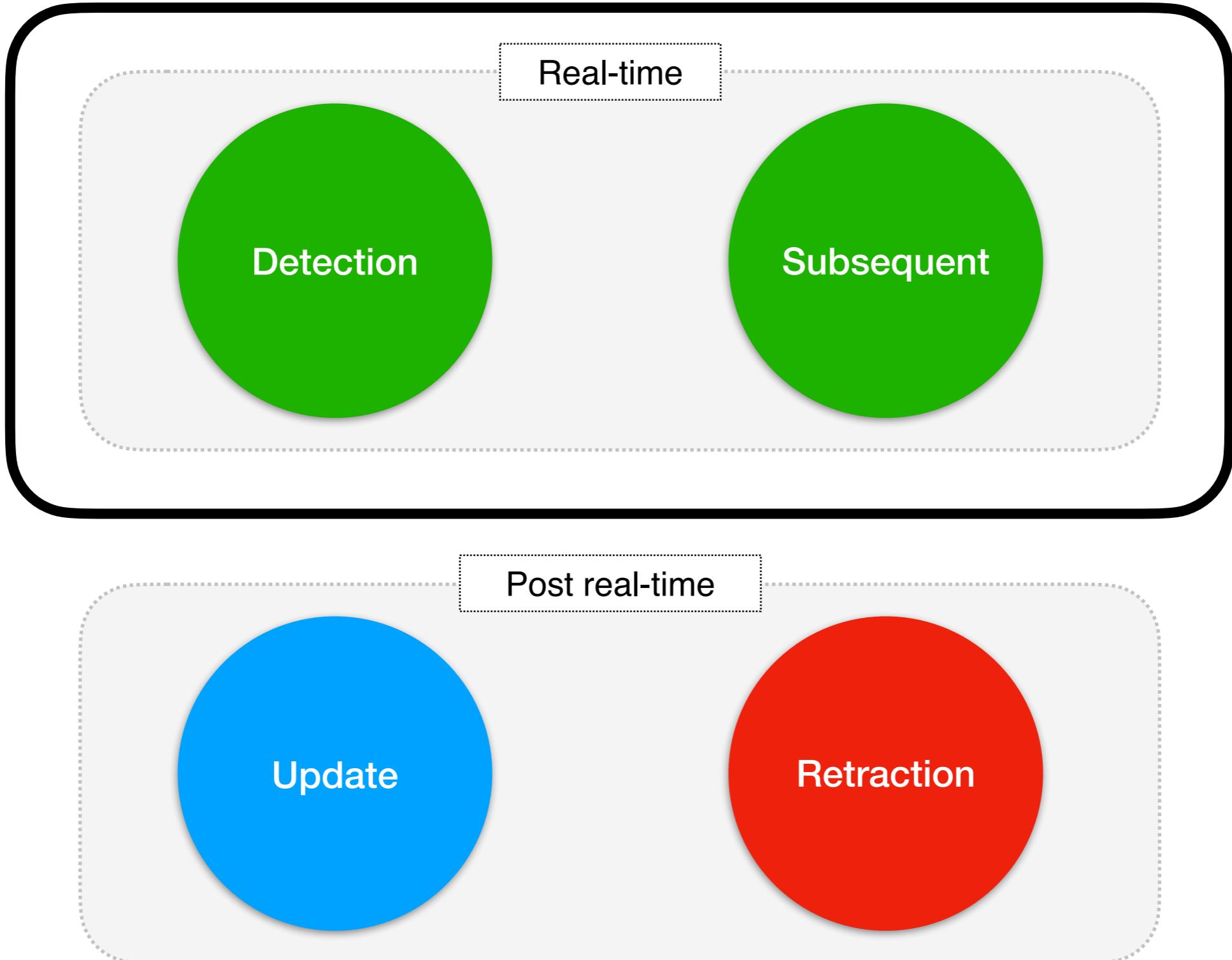
## Key Features

- ▶ A new medium for reporting FRB observations in a machine-readable format.
- ▶ Prescribes four types of VOEvents for FRB observations.

## Use Cases

- ▶ CHIME/FRB implements all four types, with some modifications and extensions.

# CHIME/FRB VOEvents



# CHIME/FRB Detection and Alert Criteria

A complete description of the real-time FRB detection pipeline is here [\[1\]](#).

All radio signals reaching the L2-L3 stage are assigned an **event number** and are referred to as Events.

If an Event satisfies the alert criteria it will be published as a VOEvent of one type:

- ▶ **Detection**, for a new FRB
- ▶ **Subsequent**, for an FRB associated with a known source

The **alert criteria** are:

- ▶  $\text{SNR} \geq 10$ ; and
- ▶ Not associated with a known Galactic source; and
- ▶ Intensity and/or baseband callback data were requested.

Published VOEvents represent a **subset** of all FRB events that are detected and further processed by CHIME/FRB.

# VOEvent XML Documents

The VOEvents are text documents styled in XML with a defined structure.

Click the **links** to go to the relevant slides.

[Link → <VOEvent \[...\]>](#)

[Link → <Who> \[...\]</Who>](#)

[Link → <What> \[...\]</What>](#)

[Link → <WhereWhen> \[...\]</WhereWhen>](#)

[Link → <How> \[...\]</How>](#)

[Link → <Why> \[...\]</Why>](#)

[Link → <Citations> \[...\]</Citations>](#)

[</VOEvent>](#)

# The <VOEvent> Section

## IVORN

- ▶ International Virtual Observatory Resource Name, similar format to a URL/URI, a unique identifying string for every VOEvent that uses ivo:// prefix.
- ▶ Example:

```
ivo://ca.chimenet.frb/FRB-DETECTION-
#2021-08-19-21:50:28.900992UTC+0000_7f17d982b325
```

## role

- ▶ “observation” for detections of new or known FRBs.
- ▶ “utility” for measurement updates or retractions (post real-time).
- ▶ “test” for fake VOEvents that are meant to test that the Service is working.

# The <Who> Section

## **AuthorIVORN**

- ▶ Shortened IVORN identifying CHIME/FRB as the author of the VOEvent.

## **Author → contactEmail**

- ▶ Reach out here for questions about CHIME/FRB VOEvents.

## **Author → contactName**

- ▶ Any communications via email can address this CHIME/FRB member.

## **Date**

- ▶ Date and time when the VOEvent XML was created.

# The <What> Section

## Overview

All relevant meta data for the observation is reported here as named parameters.

Values originate from the real-time FRB detection pipeline.

### Observatory Parameters

backend  
bandwidth  
bits\_per\_sample  
centre\_frequency  
npol  
sampling\_time  
tsys

### Event Parameters

dm  
dm\_error  
event\_no  
event\_type  
known\_source\_name  
pipeline\_name  
pos\_error\_semi-major\_deg\_95  
pos\_error\_semi-minor\_deg\_95  
snr  
timestamp\_utc  
timestamp\_utc\_error

### advanced parameters

dm\_gal\_ne\_2001\_max  
dm\_gal\_ymw\_2016\_max  
timestamp\_utc\_inf\_freq  
timestamp\_utc\_inf\_freq\_error

# The <What> Section

## Observatory Parameters

backend

bandwidth

bits\_per\_sample

centre\_frequency

npol

sampling\_time

tsys

### **backend**

- Real-time FRB search backend produced these meta data.

### **bandwidth**

- Nominal CHIME receiving bandwidth is 400 MHz (400 - 800 MHz).

### **bits\_per\_sample**

- The raw intensity data consists of 16384 frequency channels at 0.983 ms cadence as 8-bit integers.

# The <What> Section

## Observatory Parameters

backend

bandwidth

bits\_per\_sample

centre\_frequency

npol

sampling\_time

tsys

### **centre\_frequency**

- ▶ Centre observing frequency of the CHIME band, 400 MHz.

### **npol**

- ▶ CHIME antennas have 2 polarizations (dual).

### **sampling\_time**

- ▶ Real-time FRB search resolution is 0.983 ms.

### **tsys**

- ▶ CHIME receiver noise temperature is 50 K.

# The <What> Section

## Event Parameters

dm  
dm\_error  
event\_no  
event\_type  
known\_source\_name  
pipeline\_name  
pos\_error\_semimajor\_deg\_95  
pos\_error\_seminor\_deg\_95  
snr  
timestamp\_utc  
timestamp\_utc\_error

### dm

- ▶ Real-time ([bonsai \[1\]](#)) dispersion measure in  $\text{cm}^{-3}$  pc of the burst.

### dm\_error

- ▶ Real-time ([bonsai \[1\]](#)) dispersion measure uncertainty with one of five values:  
 $[0.404, 0.404, 0.809, 1.62, 3.24] \text{ cm}^{-3}$  pc.

### event\_no

- ▶ CHIME/FRB internal event number.
- ▶ Assigned at L2-L3 in the event registration process.
- ▶ Use this in all communications with CHIME/FRB regarding individual VOEvents.

# The <What> Section

## Event Parameters

dm

dm\_error

event\_no

event\_type

known\_source\_name

pipeline\_name

pos\_error\_semimajor\_deg\_95

pos\_error\_seminor\_deg\_95

snr

timestamp\_utc

timestamp\_utc\_error

### event\_type

- ▶ Real-time event classification based on comparison of DM with Galactic DM estimates.
- ▶ EXTRAGALACTIC or AMBIGUOUS.

Extragalactic:  $DM - M > 5\sigma$

Ambiguous:  $5\sigma \geq DM - M > 2\sigma$

Galactic:  $2\sigma \geq DM - M$

where  $\sigma$  is the uncertainty in the DM measurement and  $M$  is given by

$$M = \max\{DM_{NE2001}, DM_{YMW2016}\} [1]$$

# The <What> Section

## Event Parameters

dm

dm\_error

event\_no

event\_type

known\_source\_name

pipeline\_name

pos\_error\_semimajor\_deg\_95

pos\_error\_seminor\_deg\_95

snr

timestamp\_utc

timestamp\_utc\_error

## known\_source\_name

- ▶ **Subsequent** alerts are published for detections of sources known both internally and publicly.
- ▶ The strength of association with the named source is measured by a probability.
- ▶ The probability of association with this source is reported in the <Why> section as the <Inference probability="..."> value in [0, 1].
- ▶ Some subsequent alerts may be associated with more than one known source; a probability is calculated for each, and only the most probable one is reported in the VOEvent.
- ▶ The known source name is either a [TNS](#) name, with format FRBYYYYMMDDx, or an internal CHIME/FRB **event number**.

# The <What> Section

## Event Parameters

dm

dm\_error

event\_no

event\_type

known\_source\_name

pipeline\_name

pos\_error\_semimajor\_deg\_95

pos\_error\_seminor\_deg\_95

snr

timestamp\_utc

timestamp\_utc\_error

### Important!

The error ellipse is not guaranteed to be axis-aligned with the local right ascension and declination directions.

### **pipeline\_name**

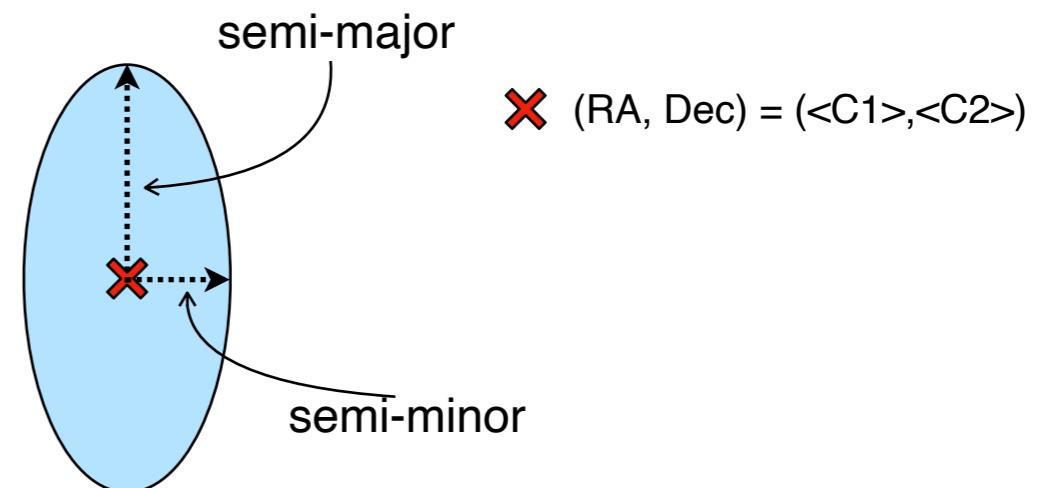
- ▶ Name of the pipeline that produced the results published in the VOEvent.

### **pos\_error\_semimajor\_deg\_95**

- ▶ Error ellipse semi-major axis to 95% confidence in degrees.

### **pos\_error\_seminor\_deg\_95**

- ▶ Error ellipse semi-minor axis to 95% confidence in degrees.



# The <What> Section

## Event Parameters

dm

dm\_error

event\_no

event\_type

known\_source\_name

pipeline\_name

pos\_error\_semimajor\_deg\_95

pos\_error\_seminor\_deg\_95

snr

timestamp\_utc

timestamp\_utc\_error

### **snr**

- ▶ Signal to noise ratio (SNR) of the detection beam.
- ▶ In the case of a multi-beam detection, the maximum SNR is reported.

### **timestamp\_utc**

- ▶ Detection time in UTC at 400 MHz after correction for dispersion, using the DM reported in the event.
- ▶ String formatted Pythonic datetime object with timezone info e.g.

`2021-09-07 12:34:56.789000+00:00`

### **timestamp\_utc\_error**

- ▶ Uncertainty in the detection time, propagated from the uncertainty in the DM.
- ▶ Float number of seconds.

# The <What> Section

## Advanced Parameters

dm\_gal\_ne\_2001\_max

dm\_gal\_ymw\_2016\_max

timestamp\_utc\_inf\_freq

timestamp\_utc\_inf\_freq\_error

### **dm\_gal\_ne\_2001\_max**

- ▶ Maximum Galactic DM along line of sight referenced from the NE 2001 model.

### **dm\_gal\_ymw\_2016\_max**

- ▶ Maximum Galactic DM along line of sight referenced from the YMW 2016 model.

# The <What> Section

## advanced parameters

dm\_gal\_ne\_2001\_max

dm\_gal\_ymw\_2016\_max

timestamp\_utc\_inf\_freq

timestamp\_utc\_inf\_freq\_error

### **timestamp\_utc\_inf\_freq**

- ▶ Detection time in UTC at infinite frequency after correction for dispersion, using the timestamp at 400 MHz, the DM, and

$$k_{DM} = \frac{1.0}{2.41 \times 10^{-4}} \text{ cm}^3 \cdot \text{s}^{-1} \cdot \text{pc}^{-1} \quad [2]$$

- ▶ String formatted Pythonic `datetime` object.

### **timestamp\_utc\_inf\_freq\_error**

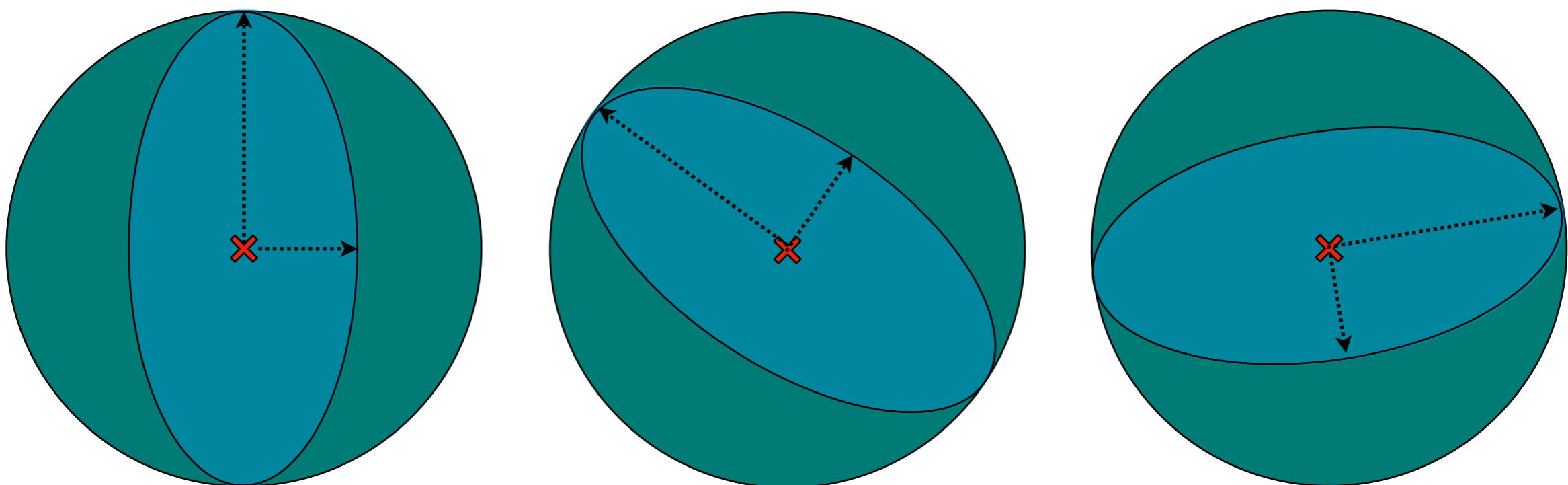
- ▶ Uncertainty in the detection time, propagated from the uncertainty in the timestamp at 400 MHz and the uncertainty in the DM.
- ▶ Float number of seconds.

# The <WhereWhen> Section

**Spatial** (localization and coordinate system) and **temporal** (arrival time) information.

The real-time localization is reported as **a circle in equatorial coordinates**.

An elliptical localization is also available in the <What> section, representing a subset of the circular region (see possible scenarios below).



✖ (RA, Dec) = (<C1>,<C2>) [see Jupyter notebook tutorial]

# The <How> Section

Currently contains a link to the CHIME/FRB public webpage: [chime-frb.ca](http://chime-frb.ca)

As the public webpage evolves and expands, we may publish links to downloadable post real-time data products from the public webpage in the VOEvent.

# The <Why> Section

The VOEvent Standard requires authors to publish an **importance** factor, a number from 0 to 1.

For observations of transient events, the number reflects the confidence in an astrophysical origin: 0 is lowest confidence, 1 is highest confidence.

The CHIME/FRB VOEvent Standard uses a real-time machine learning score from 0 to 1 to indicate this confidence, with an **internal threshold of 0.9**.

Additionally, a **probability** is reported *for subsequent alerts only* to indicate the likelihood of association with a known source.

Only the most likely association is reported, and the known source may be internal to CHIME/FRB or catalogued publicly.

- ▶ Integers of (e.g. 60792403, 183253678) are **CHIME/FRB event numbers**.
- ▶ Names formatted “FRB YYYYMMDDx” are **TNS names**.

# The <Citations> Section

All VOEvents are citable in a basic way by their VOEvent IVORN.

Citations contain the VOEvent IVORN for a previous publication.

Subsequent VOEvent

- ▶ A **follow-up** observation that cites a previous detection.

Retraction VOEvent

- ▶ Offline **retraction** of a previous FRB, either detection or subsequent.

Update VOEvent

- ▶ Offline analysis results that **supersede** a previous detection or subsequent.

# Thresholds, Data Quality, and Performance

# Selecting Your Own Thresholds

Parameter	Data Type	Example Scenarios	
dm	float	Low-DM targets	→
event_type	str	Study AMBIGUOUS events only	→
known_source_name	str	Trigger on specific repeating FRBs	→
pos_error_semimajor_deg_95	float	Estimate chance coincidence probability for FoV	→
pos_error_semiminor_deg_95	float		
snr	float	High-SNR low-DM targets for potentially nearby FRBs	→
timestamp_utc	str	Trigger to search for temporal coincidences or afterglows	→
timestamp_utc_inf_freq	str		
Right Ascension	float	Trigger on coordinates in observatory FoV	→
Declination	float		

**Table 1:** Example thresholding scenarios for individual CHIME/FRB VOEvent meta data. Note that a general follow-up campaign will likely combine several scenarios into one. (Arrows link to a slide with more details on the parameter.)

# Recommended SNR Thresholds

		Alert Type	Tier 1	Tier 2	Tier 3
Rate [day^-1]	FRB Candidates	Detection	0.88	0.94	1.04
	Non-FRB Candidates	Subsequent	0.16	0.18	0.19
	FRB Candidates	Detection	0.14	0.29	0.34
	Non-FRB Candidates	Subsequent	0.00	0.00	0.00
		$SNR \geq 12$	$SNR \geq 11$	$SNR \geq 10$	

**Table 2:** Average daily rate of VOEvents published between 17 June 2021 and 2 September 2021 (77 days). The rates are split by those events that were verified as FRBs (true positives) or non-FRBs (false positives) by humans **after** the VOEvent was published.

# Alert Latency by Type

A basic latency measurement is defined as the difference in time between detection at 400 MHz and publication to the VOEvent Network.

**Additional delays due to Internet traffic and routing between broadcaster and subscriber are not accounted for.**

	Counts	Average Latency [s]	Standard Deviation [s]
<b>Detection</b>	149	12.42	3.92
<b>Subsequent</b>	19	12.99	3.07

**Table 3:** VOEvent latency by alert type between 17 Jun 2021 to 2 Sep 2021, reported as average and standard deviation over the 77 day period.

# Alert Latency by Verified Class



**Figure 1:** Latency of VOEvents published from 17 Jun 2021 to 2 Sep 2021. Post real-time human verification status is indicated by green for FRB Candidates and red for non-FRB Candidates. Most VOEvents are published with a latency of 10 to 20 seconds with respect to the detection at 400 MHz.

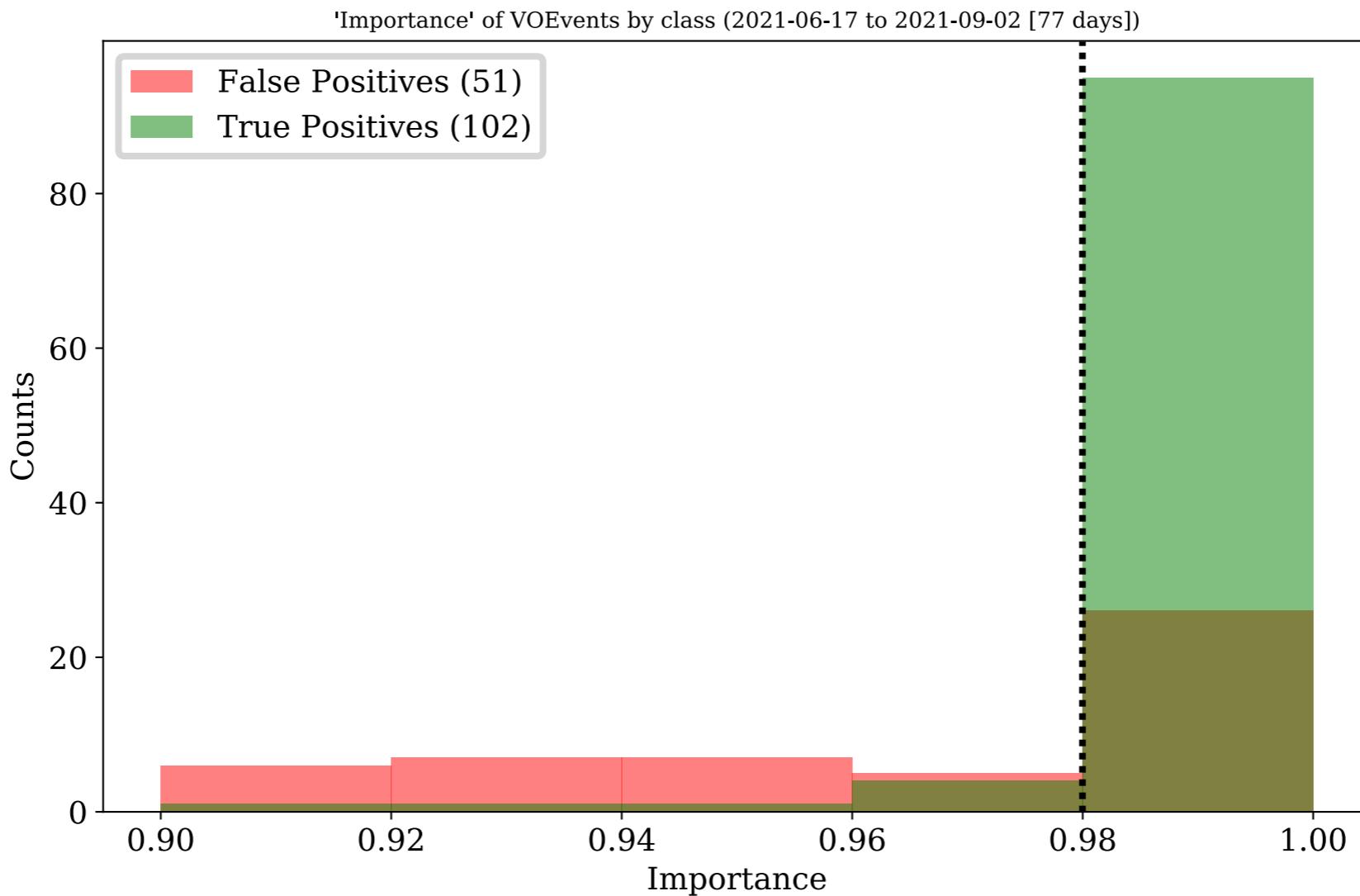
# Data Quality

The **importance** value of CHIME/FRB VOEvents is the best available real-time indication of data quality.

The value reflects a score in [0, 1.0] of the real-time machine learning classifier that attempts to distinguish two classes: Astrophysical, and RFI.

Internally a cut of 0.9 is applied before publishing a VOEvent, but subscribers are encouraged to **consider a higher cut of 0.98** to achieve a lower false positive rate.

# Data Quality Factors



**Figure 2:** Importance value of VOEvents published from 17 Jun 2021 to 2 Sep 2021. Post real-time human verification status is indicated by green for FRB Candidates and red for non-FRB Candidates.

# Misclassifications and False Associations

## (1) RFI Contamination

- The real-time machine learning classifier has a non-zero false positive rate.

## (2) Galactic Source Contamination

- Uncertainty of Galactic electron density maps (NE2001, YMW 2016).

## (3) Incorrect Association with a Known FRB

- An event is detected and associated by chance with a known FRB.
- Tends to be more common for events detected in the  $\delta \gtrsim 70^\circ$  regime, related to the fact that CHIME has twice daily sky exposure in this range [2].

# Real-time Localization Challenges

Single beam events are published with the sky coordinates of the beam centre.

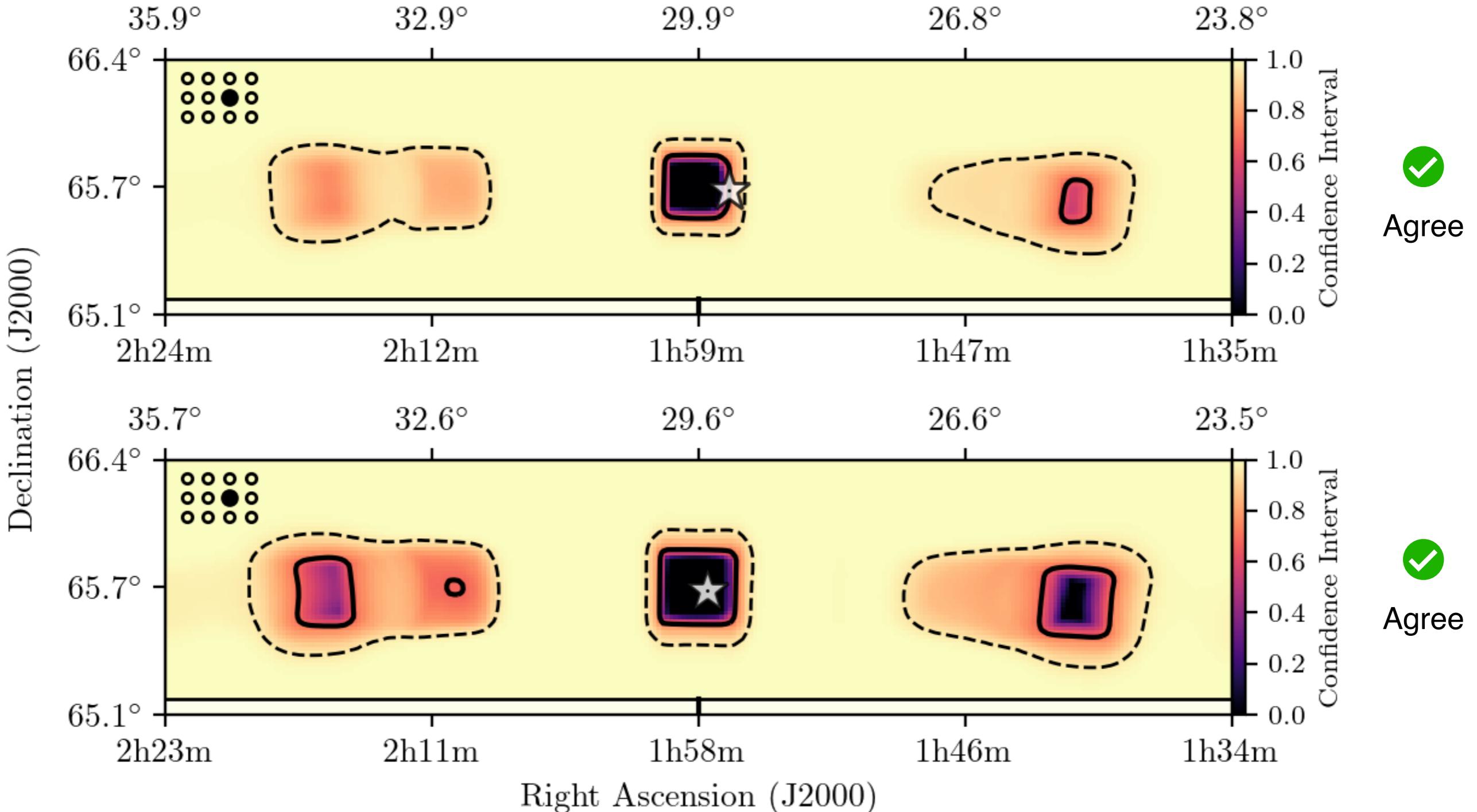
## (1) Side-lobe detection

- Off-meridian sensitivity of formed beams to **very bright events** results in a **side-lobe event**.

## (2) SNR clipping

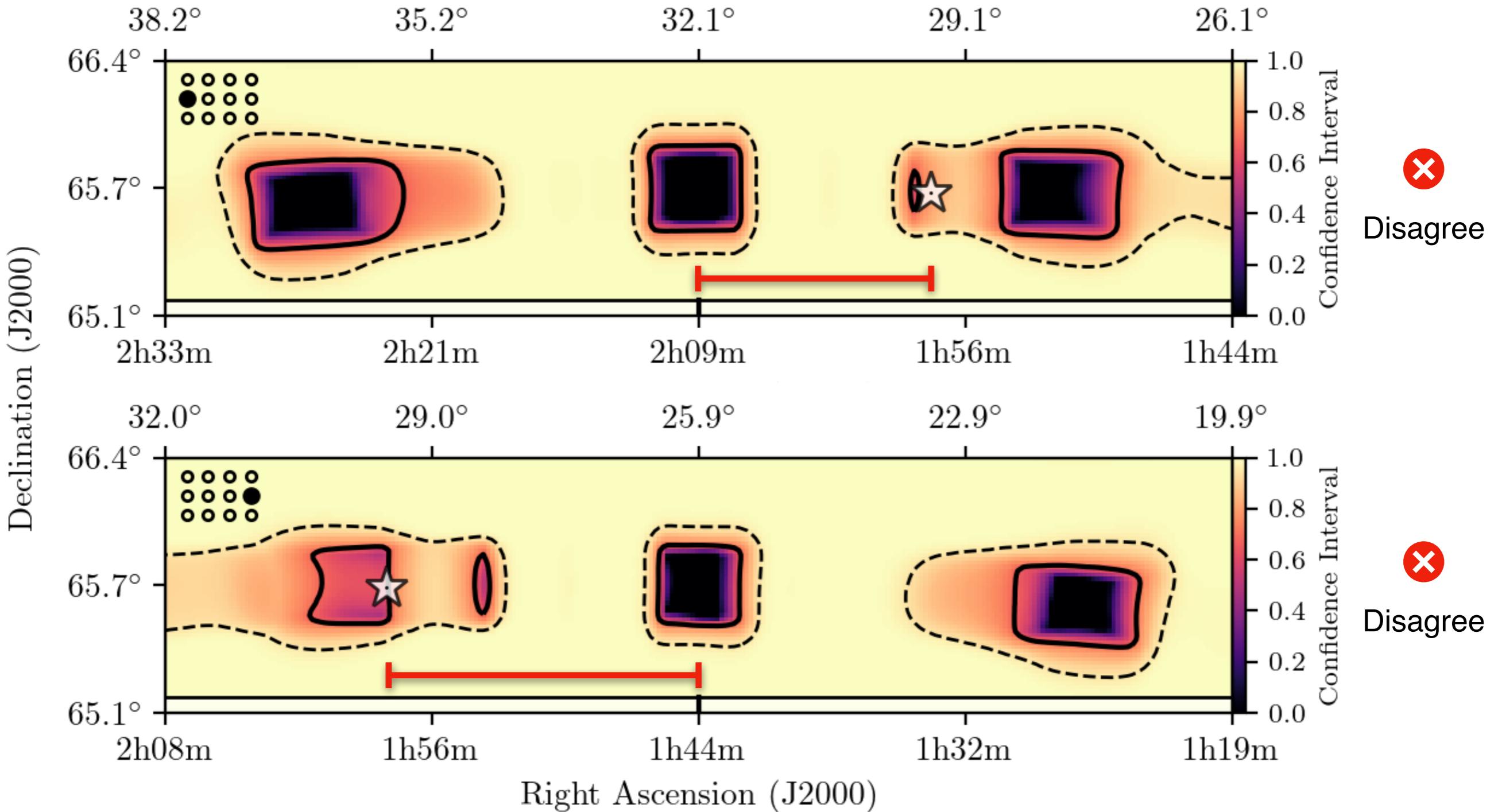
- Very bright multi-beam events lead to **clipping** of the max SNR.
- Clipping confuses the real-time localization algorithm, resulting in potentially bad central coordinates and error region.

# Real-time Localization Challenges



**Figure 4:** The true location of FRB 20180916B (star) is shown against the detection beam and its first side lobes, for two different events from the source. The method of pulsar analogues was used (see [3]) to produce the  $\chi^2$  surface and the 68% (solid) and 95% (dashed) confidence contours. The beam detection pattern is shown in the top left of each subplot. The beam centre is indicated by the black tick along the horizontal axis. The star and the black tick agree, indicating an accurate real-time localization. Figure courtesy of A. Josephy.

# Real-time Localization Challenges



**Figure 5:** The true location of FRB 20180916B (star) is shown against the detection beam and its first side lobes, for two different events from the source, with contours colour scale, and all markings as in **Figure 4**. The disagreement between the star and black tick point to a side lobe detection. Figure courtesy of A. Josephy; see [3] for more details.

# Service Outages and Downtime

**Interruptions** to the VOEvent Service should be expected and all follow-up observers should **design campaigns** with this consideration in mind.

Notifications of prolonged outages will be provided on a **best-effort basis via email** to the address provided during the subscription process.

Be sure to monitor **junk/spam** for important notices.

## Upstream

- ▶ CHIME telescope up-time fluctuations:
  - Unplanned power or network loss
  - Planned upgrade cycles

## Downstream

- ▶ McGill Comet broker up-time fluctuations:
  - Unplanned power or network loss
  - Planned upgrade cycles

# Post Real-time Alerts

# CHIME/FRB VOEvents



# Real-time Alerts may be Retracted

Detection and subsequent VOEvents are subject to **retraction**, issued once per day.

Refer to the Jupyter notebook [tutorial](#) for further details.

The subscriber should **forego** planned follow-up of retracted alerts.

## Retraction Scenarios

1. False positive due to RFI contamination
  - ▶ RFI mitigation is not perfect and is under iterated improvement.
2. Mis-association with known source (Galactic, or FRB)
  - ▶ Side lobe detections of bright pulsars e.g. the Crab Nebula pulsar.
  - ▶ Higher chance coincidence probability in certain sky regions ( $\delta \gtrsim 70^\circ$  [2]).

# Real-time Alerts may be Updated

The following represent **future enhancements** to the VOEvent Service.

**Latency** is hard to estimate but could be hours to days.

**Update VOEvent #1:** Transient Name Server (TNS) object name

- ▶ Published after successful submission to the TNS.

**Update VOEvent #2:** Miscellaneous post-processing analysis

- ▶ Maximum redshift from Macquart relation.
- ▶ Chance coincidence probability.

**Update VOEvent #3:** Intensity analysis

- ▶ Data products from analysis of the dynamic spectrum and intensity localization.

**Update VOEvent #4:** Baseband analysis

- ▶ Data products from analysis of the raw voltages and baseband localization.

# Conclusion

# Summary

Questions that have been addressed in this presentation include:

1. What is the CHIME/FRB VOEvent Service?
2. How can I connect to the Service?
3. Where can I access additional help resources?
4. What is a VOEvent? What is an FRB VOEvent? How is CHIME/FRB using them?
5. What information is contained in a CHIME/FRB VOEvent?
6. I received a VOEvent from CHIME/FRB; how do I extract information from it?
7. How can I place thresholds on VOEvents that are meaningful for my follow-up campaign?
8. What thresholds does CHIME/FRB recommend for data quality?
9. How long will it take for me to receive a VOEvent after an FRB is detected?
10. I received a VOEvent from CHIME/FRB; how do I know if its a real FRB or not?
11. How accurate and precise are the localizations published in real-time VOEvents?
12. I have not received a VOEvent in a while; is there a problem with the Service?
13. What is next for the Service?

# Stay Tuned for More!



Photo credit: CHIME Collaboration



# References

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