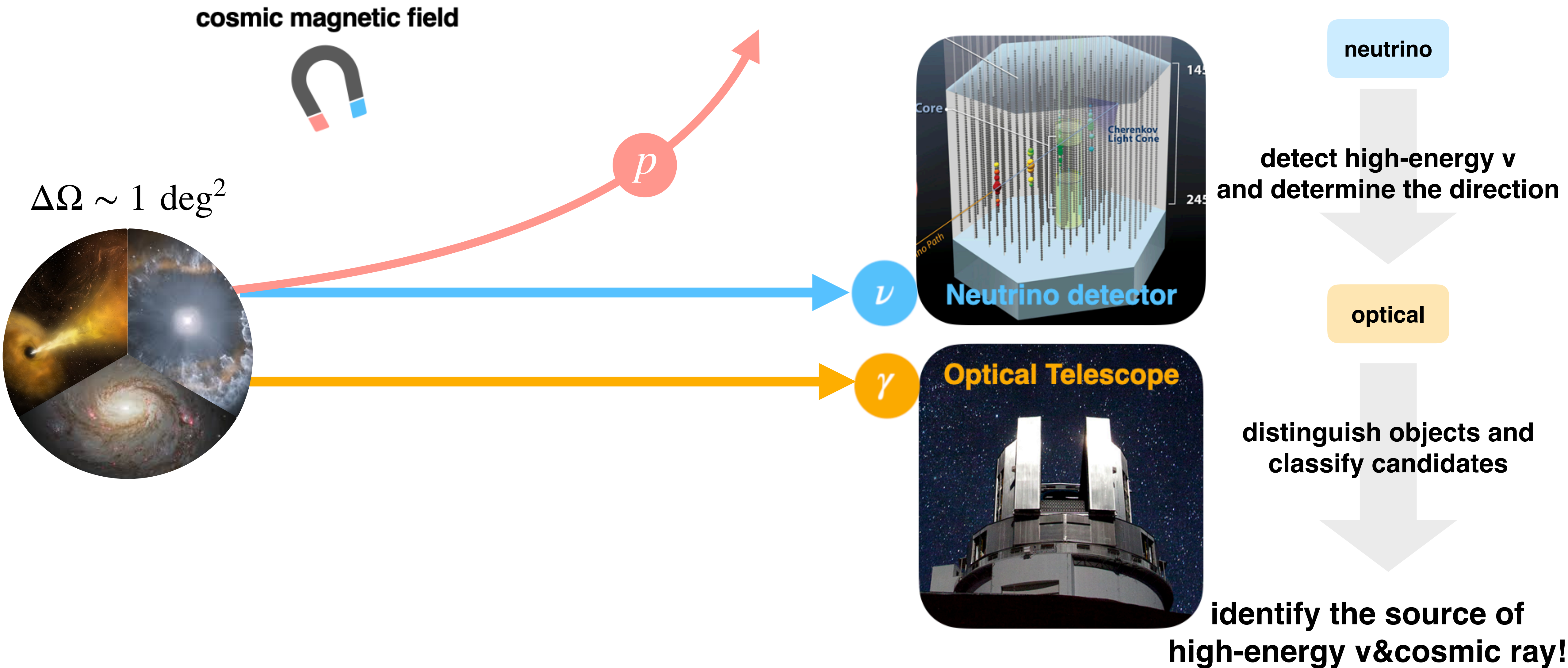


# **Constraining High-Energy Neutrino Transients by IceCube Neutrino Multiplet Event: optical counterpart search**

**Seiji Toshikage (Tohoku University)**

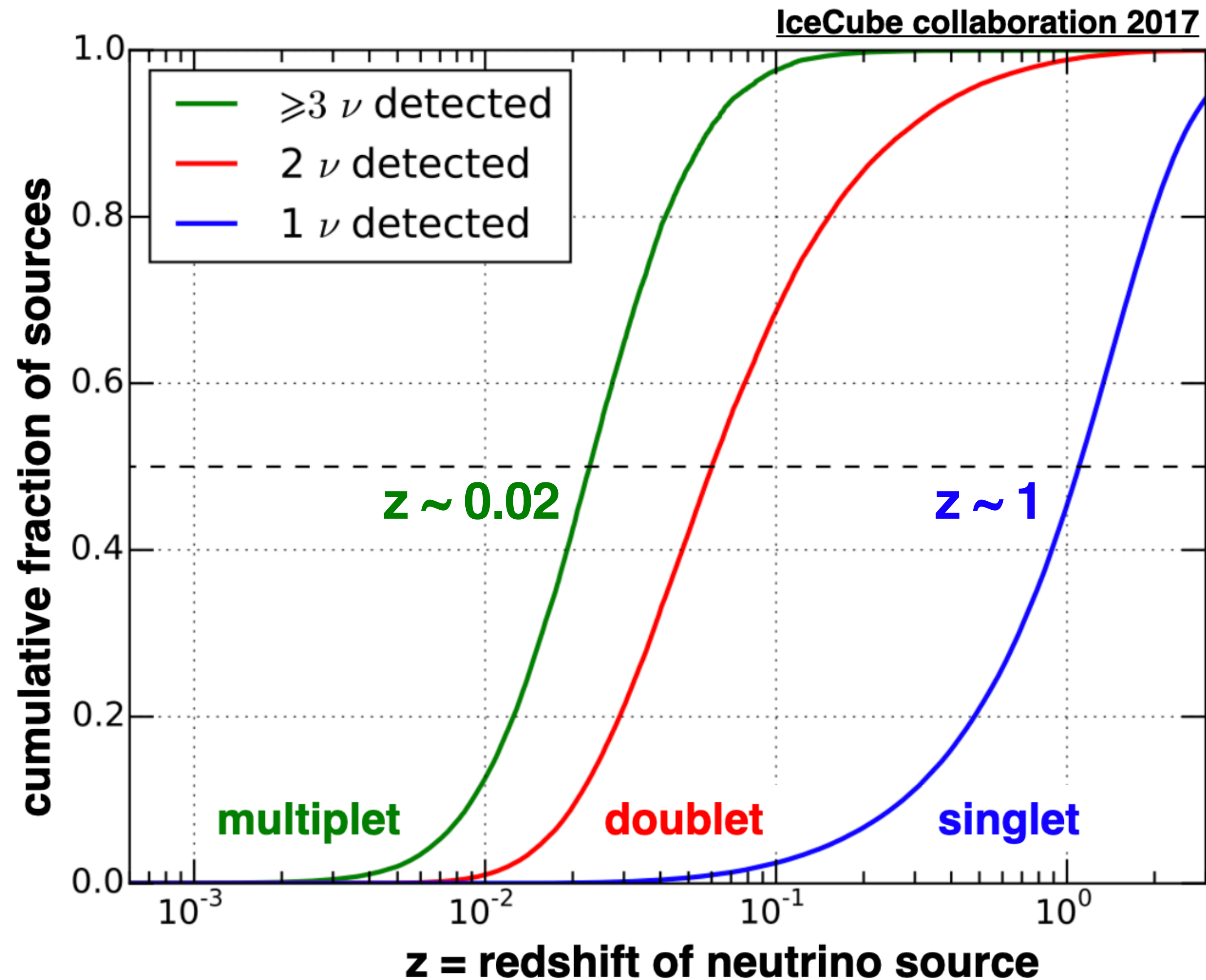
in collaboration with Masaomi Tanaka, Shigeo Kimura (Tohoku U.),  
Tomoki Morokuma (CIT), Nozomu Tominaga (NAOJ),  
Shigeru Yoshida, Nobuhiro Shimizu, Wataru Iwakiri (Chiba U.)

# Method: Strategy for the identification of cosmic ray source



**neutrino + EM wave (optical) is a powerful tool**

# Multiple neutrino signal and distance to the source

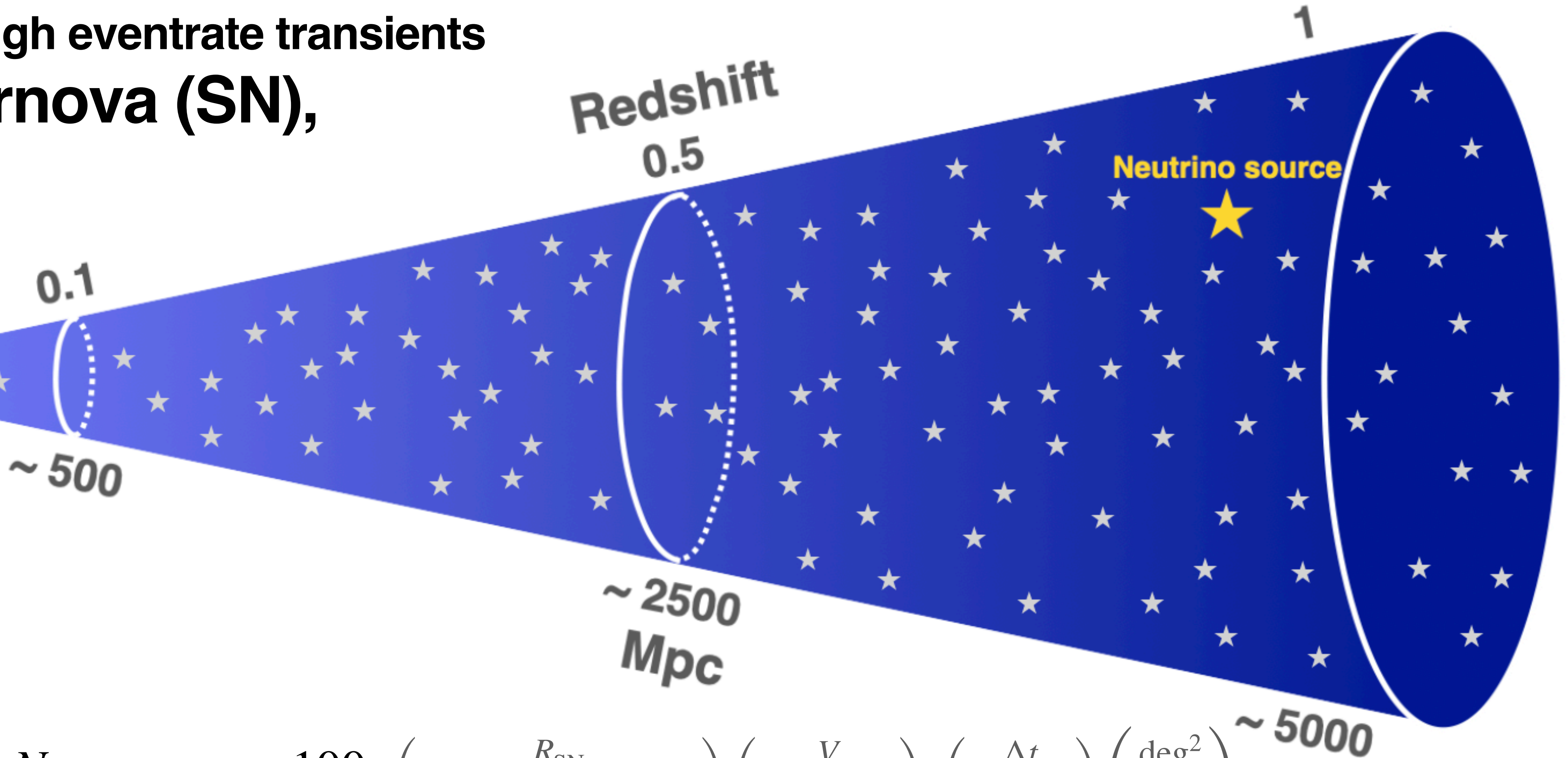


Number of neutrino detections can be a distant indicator

# Single neutrino detection = “Singlet”

Assuming high eventrate transients  
e.g., **Supernova (SN)**,

$$\Delta\Omega \sim 1 \text{ deg}^2$$

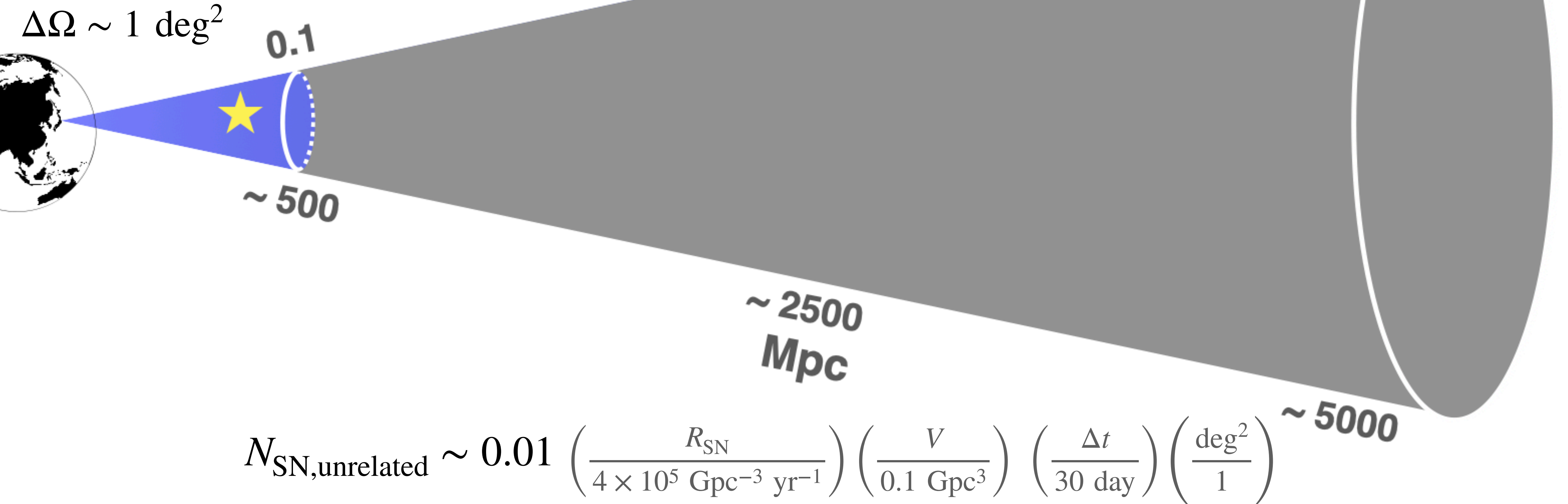


$$N_{\text{SN,unrelated}} \sim 100 \left( \frac{R_{\text{SN}}}{4 \times 10^5 \text{ Gpc}^{-3} \text{ yr}^{-1}} \right) \left( \frac{V}{10^2 \text{ Gpc}^3} \right) \left( \frac{\Delta t}{30 \text{ day}} \right) \left( \frac{\text{deg}^2}{1} \right) \sim 5000$$

Number of unrelated SNe is **too large** to discuss association

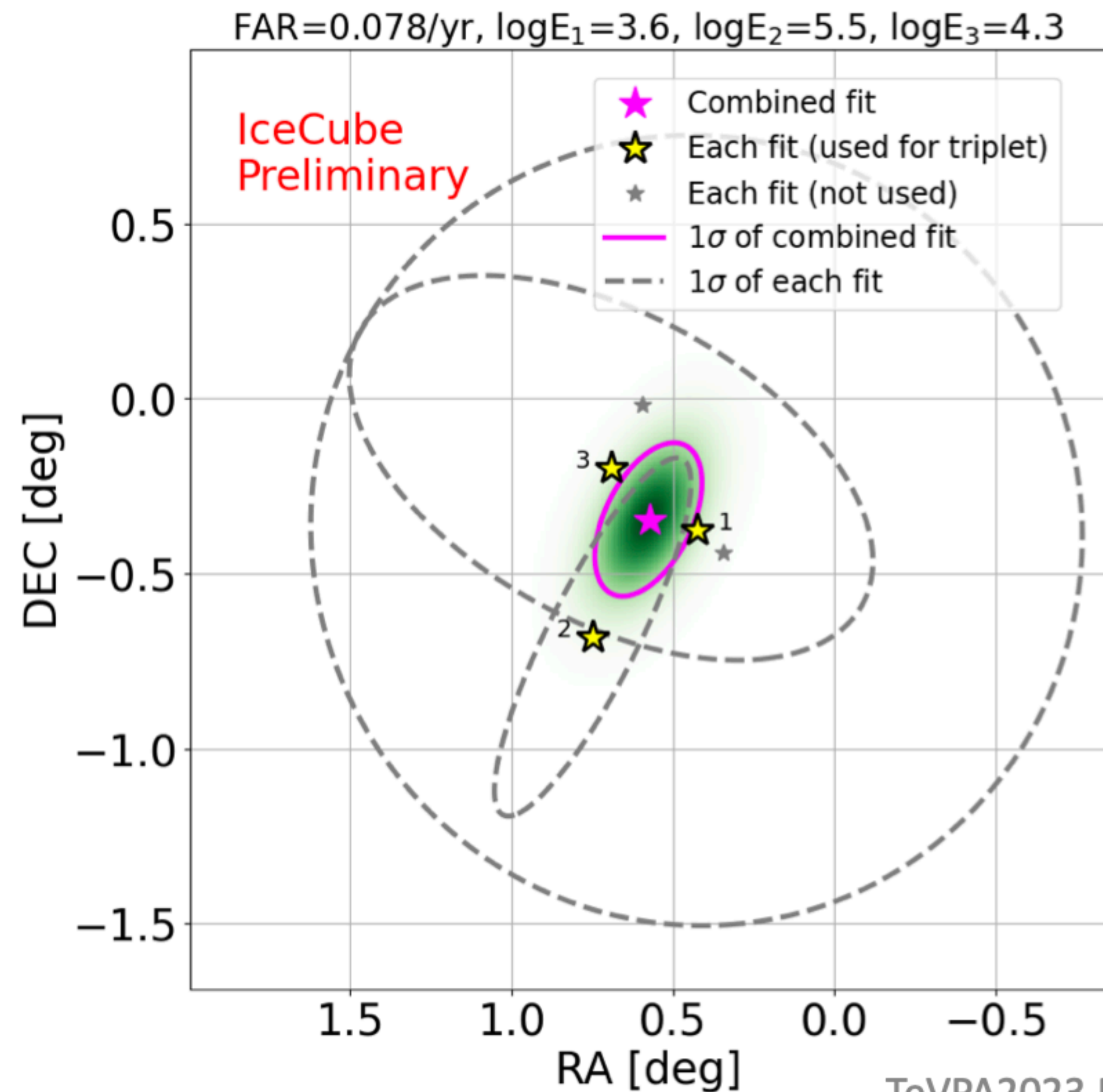
# Multiple neutrino detection = “Multiplet”

Assuming high eventrate transients  
e.g., **Supernova (SN)**,



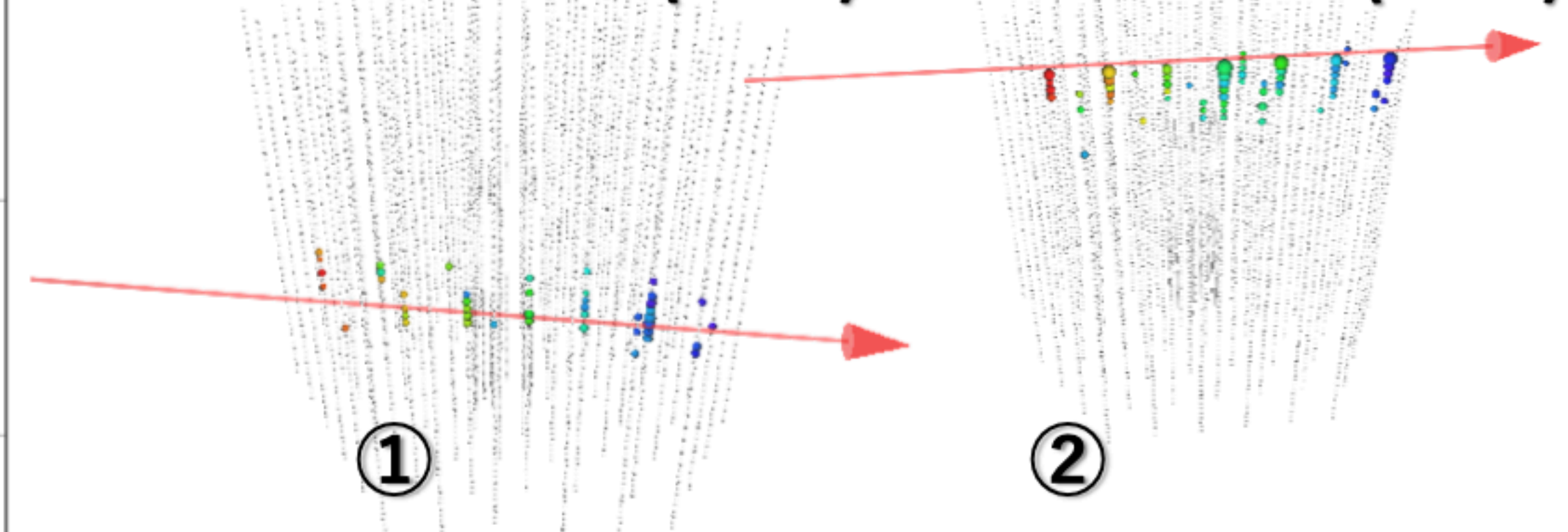
Number of unrelated objects become **small enough** to discuss association

# Triplet neutrino reported by IceCube team (Shimizu-san's talk)

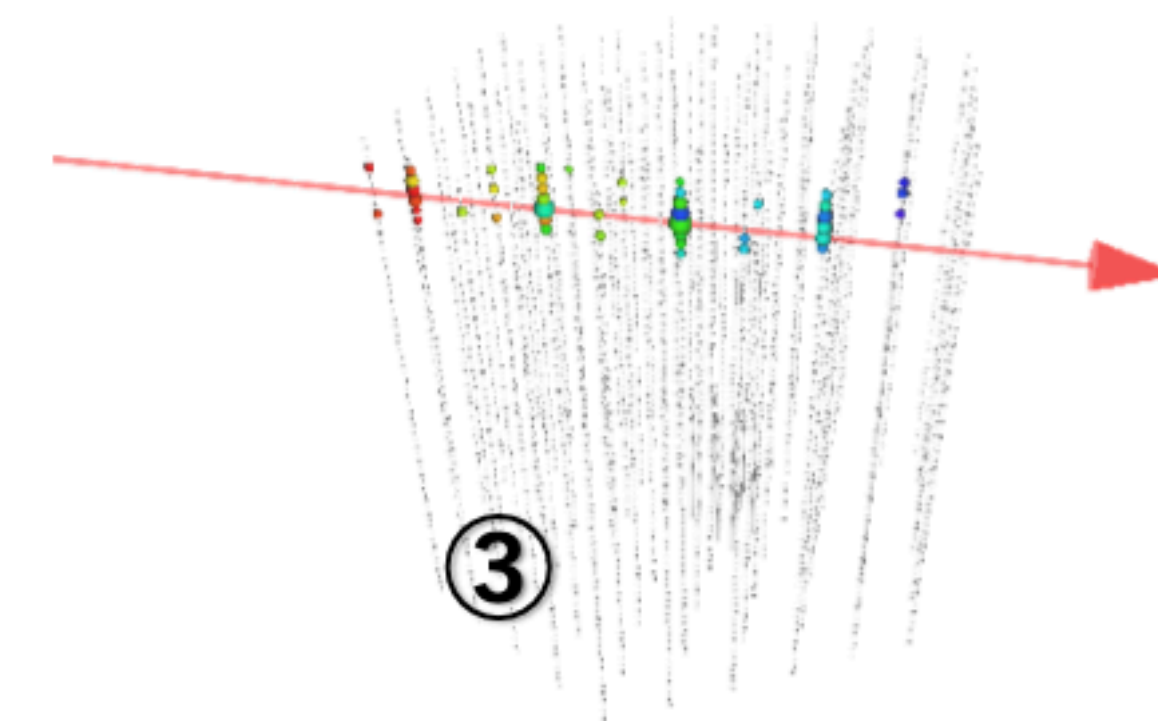


TeVPA2023 Nobu (Chiba Univ.)

2020 June 27th (15:45) 2020 June 11th (05:22)



2020 June 15th (10:58)



Based on this event, we developed optical counterpart search strategy for triplet

# This work: optical counterpart search for multiplet event

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## IceCube Multiplet event in June 2020

Zwicky Transient Facility (ZTF) team monitored that region

-> No transients have been reported based on their alert stream

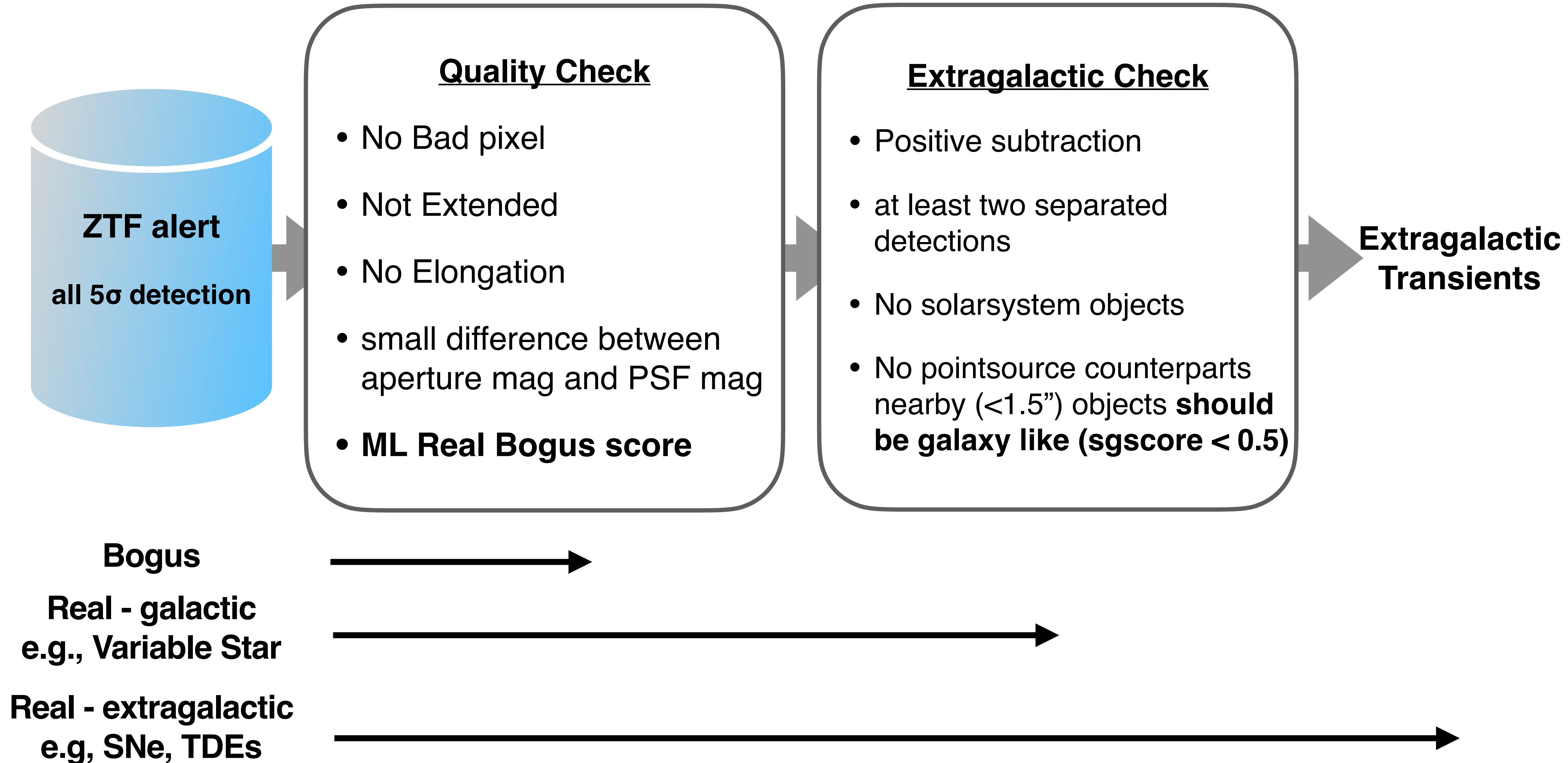
- How accurate is the alert stream in passing through real transients?
- How many unrelated objects pass the stream?



**For testing the association of transients and multiplet event accurately, we reconstructed the alert stream for optical counter part of multiplet focusing on**

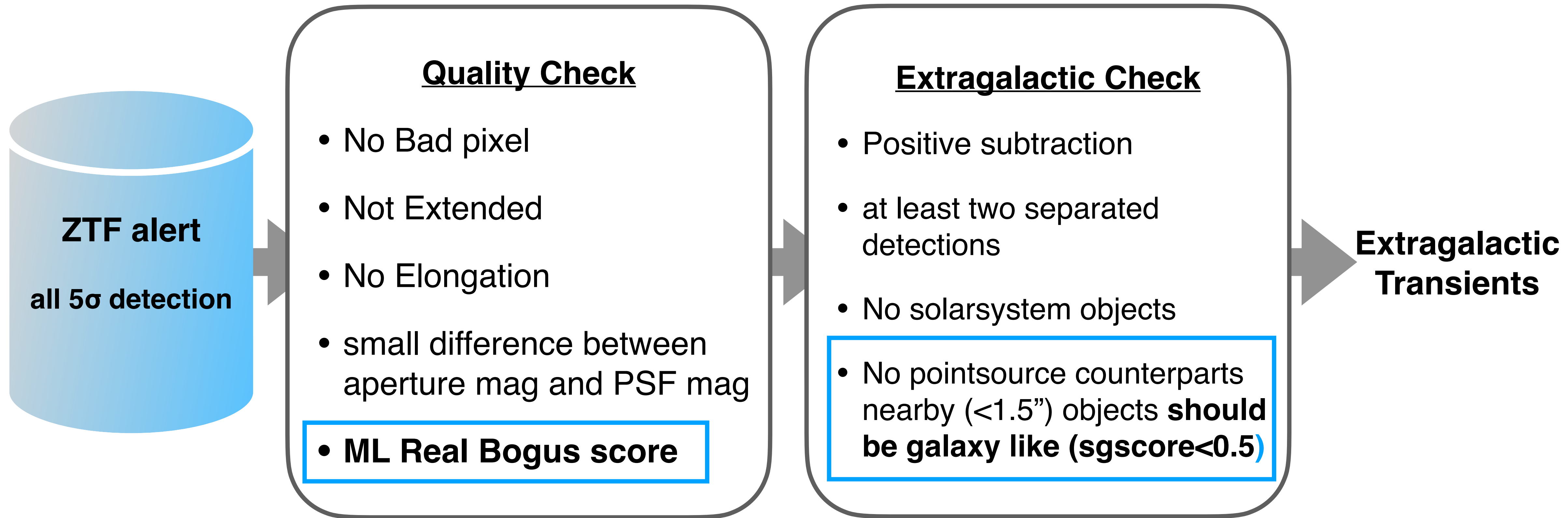
- True Positive Rate (TPR)
- Number of background events

# ZTF reported “no transients” through alert stream





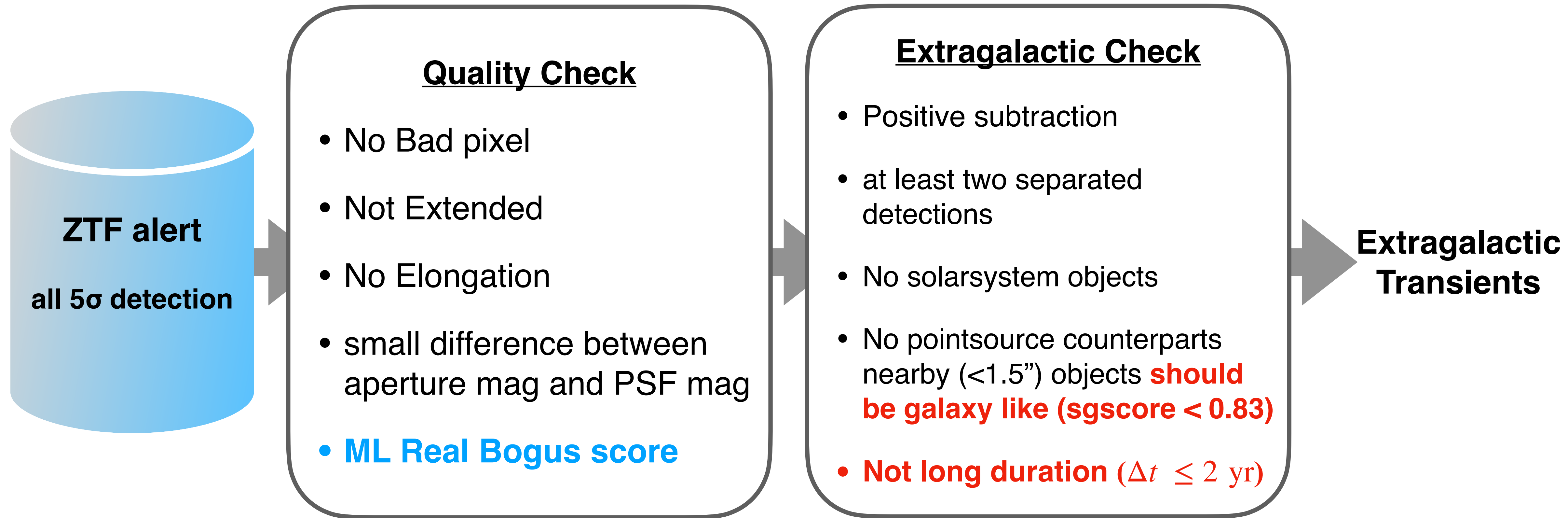
# ZTF reported “no transients” through alert stream



**We should check or even modify**

**Behavior of some criteria in ZTF alert stream is not fully understood**  
e.g., real/bogus score, star/galaxy score with Machine Learning

# Our strategy of optical counterpart search for IC multiplet



We modified some criteria for higher TPR and specialized for multiplet source

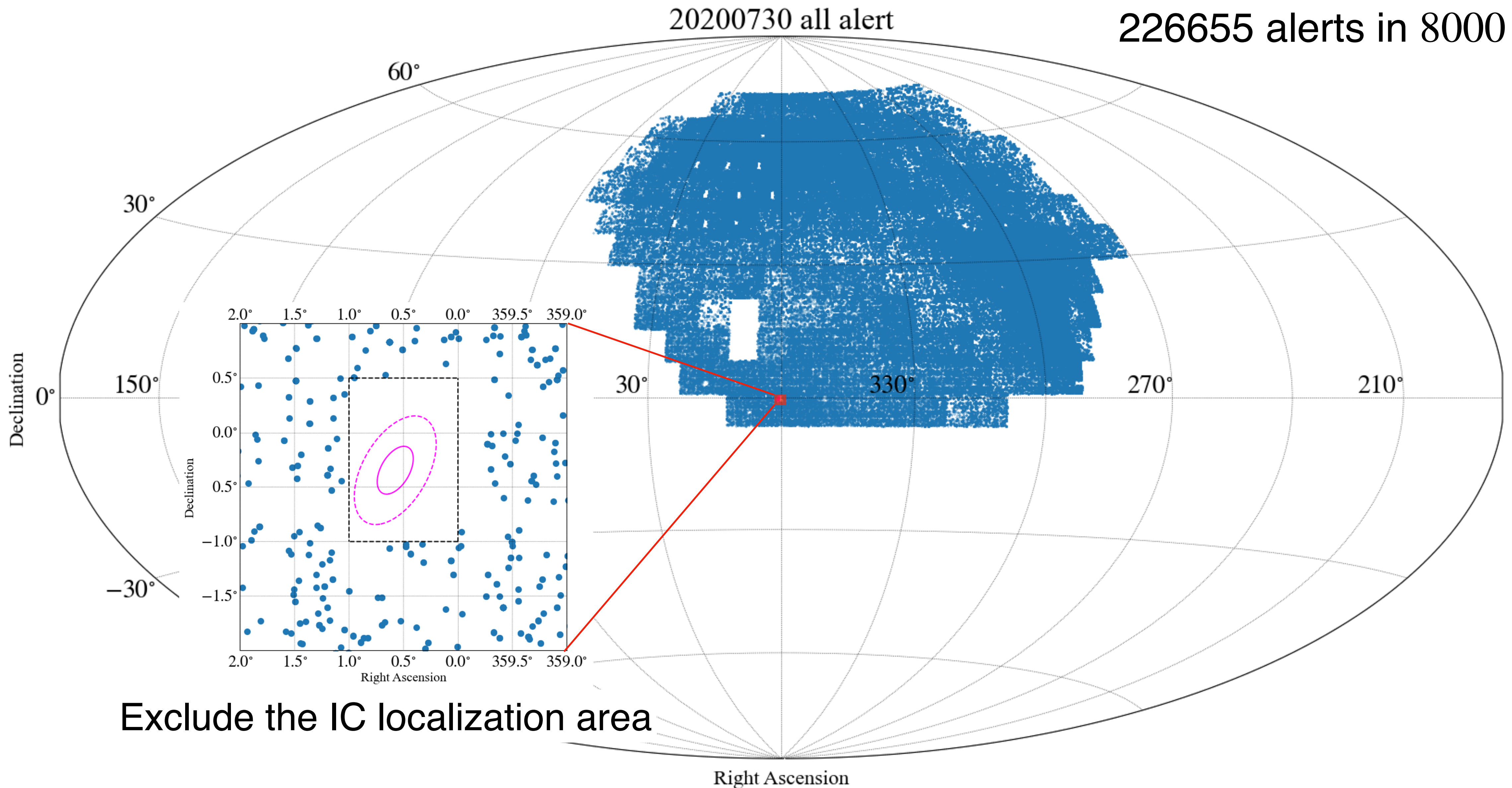
- **star/galaxy score  $< 0.83$  is TPR = 0.995 (Tachibana&Miller 2018)**
- **Not long duration -> focusing on the short duration transients (multiplet time window = 30 day)**

**We estimated number of unrelated objects and TPR with control region**

# Validate our criteria with control data - all alerts

20200730 all alert

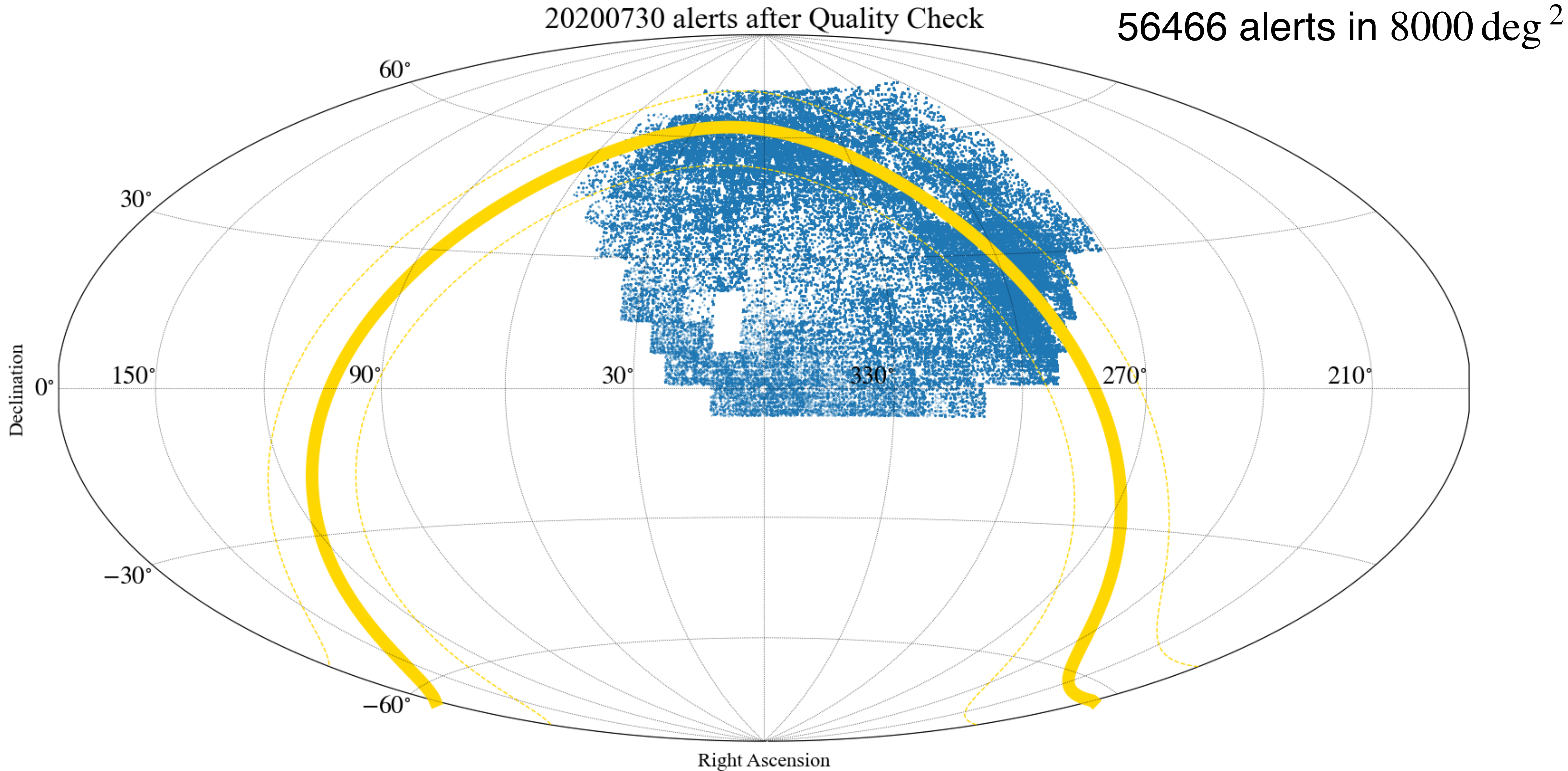
226655 alerts in 8000 deg<sup>2</sup>



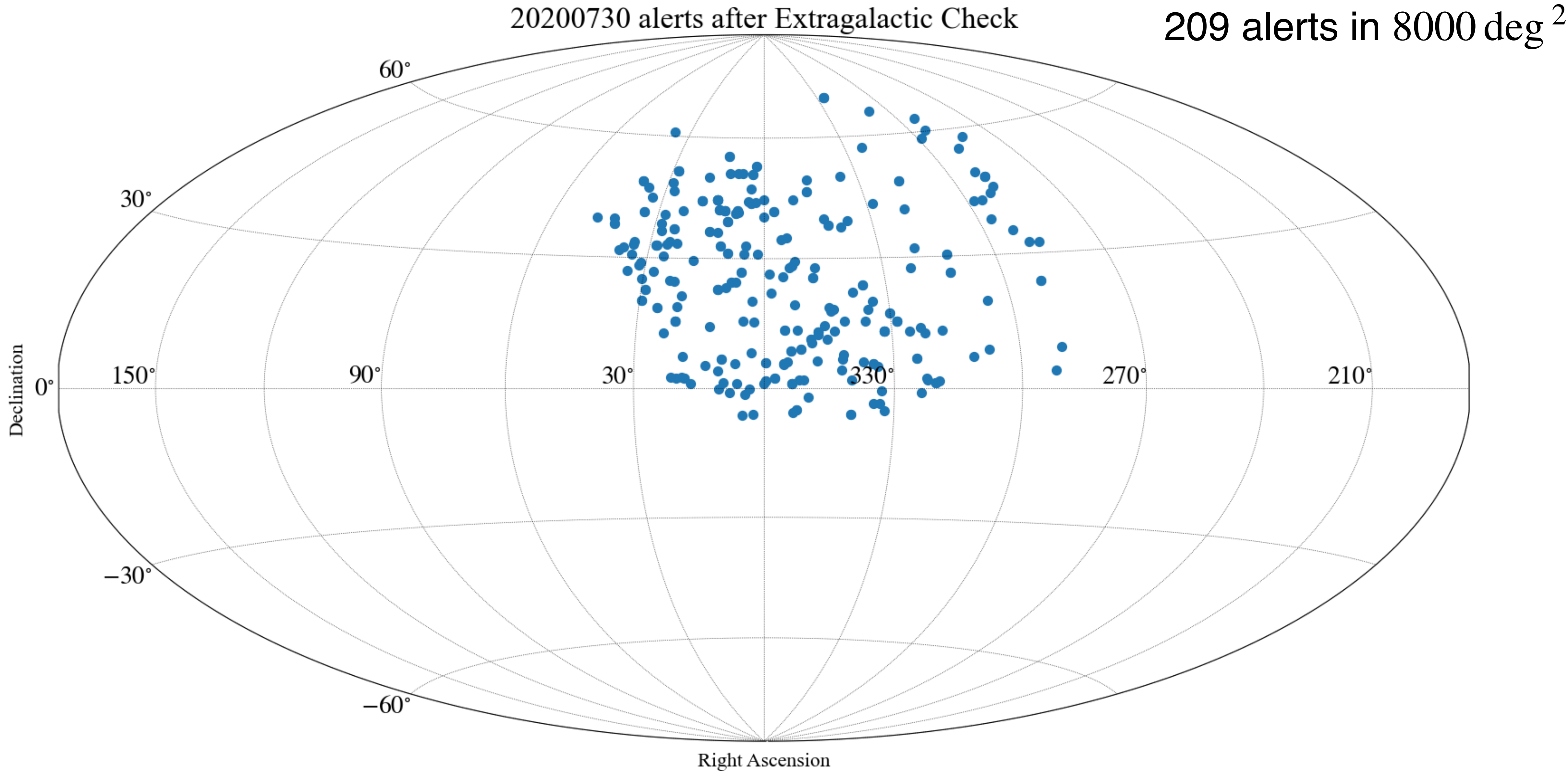
# Validate our criteria with control data - Quality Check



# Validate our criteria with control data - Quality Check



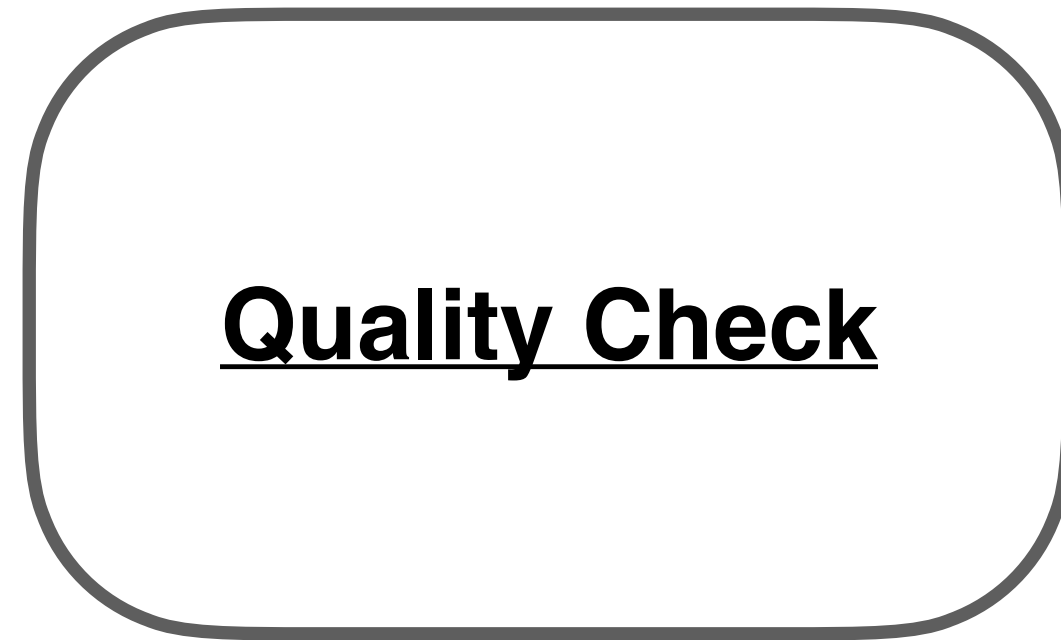
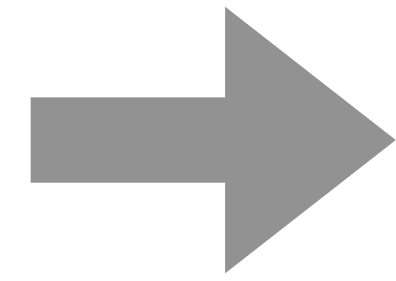
# Validate our criteria with control data - Extragalactic Check



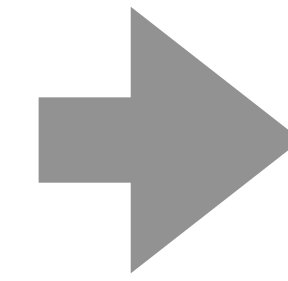
# Number of background events



All alerts  
(Including bogus)



Real transients  
(Including variable star, AGN, ...)



Extragalactic transients  
(SNe, TDEs)

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# of alerts  
in  $8000 \text{ deg}^2$

226655

56466

209

---

# of alerts  
in  $1 \text{ deg}^2$

30

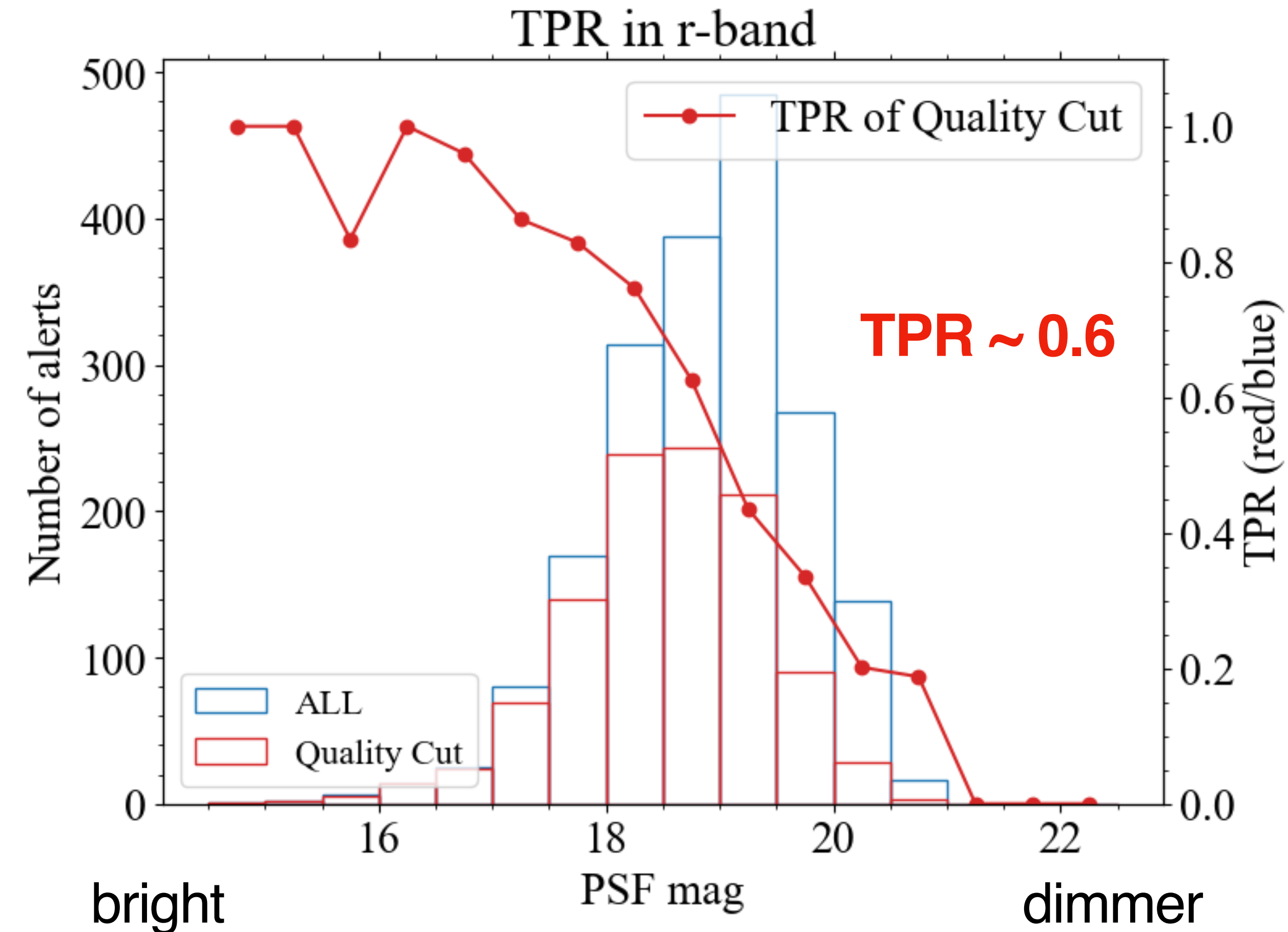
7

0.03

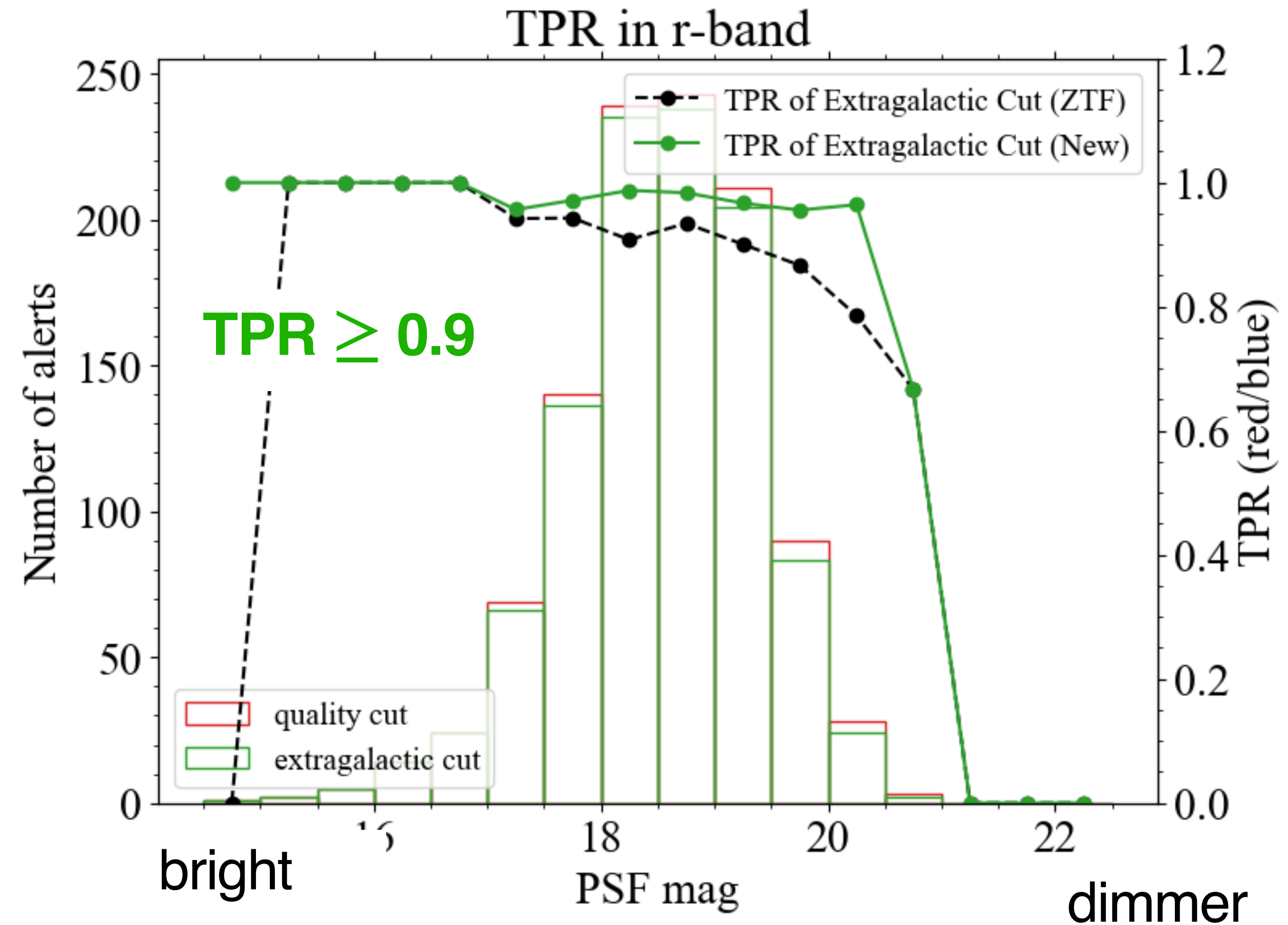
**Number of background events  $\leq 0.03 \text{ deg}^{-2}$  even without distance information**

# True Positive Rate (passing rate) estimation with reported transients

## Quality Check



## Extragalactic Check



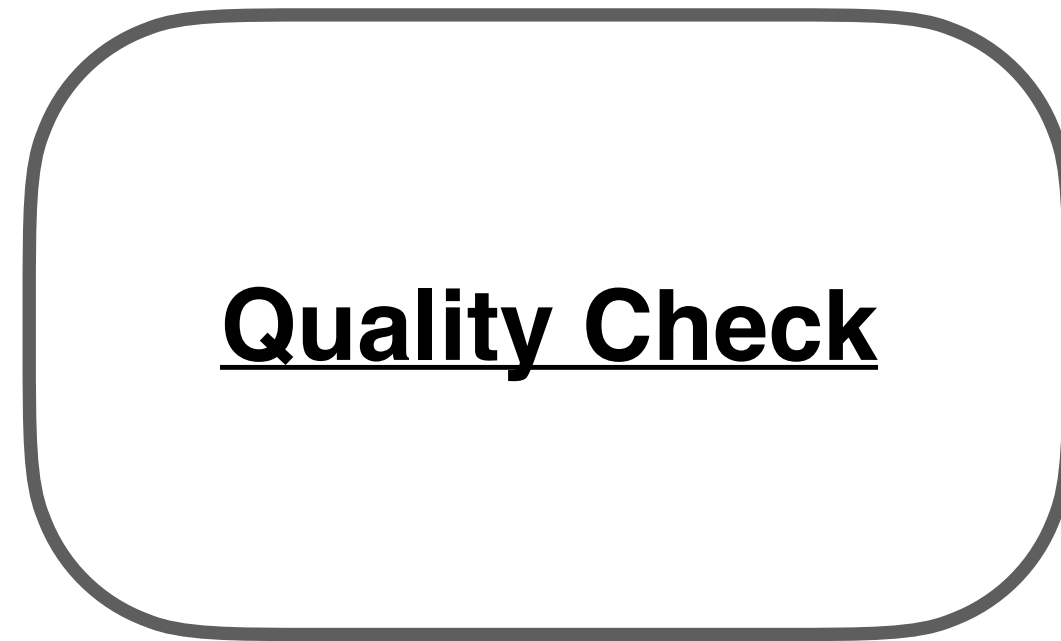
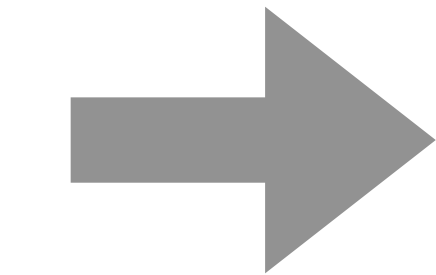
We checked the TPR of Quality Check and improved the TPR of Extragalactic Check



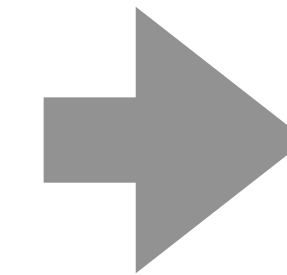
# True Positive Rate (passing rate) of new alert stream



All alerts  
(Including bogus)



Real transients  
(Including variable star, AGN, ...)



Extragalactic transients  
(SNe, TDEs)

# of alerts  
in 1 deg<sup>2</sup>

30

7

**0.03**

$$\text{TPR} = \frac{\text{TP}}{\text{TP} + \text{FN}}$$

—

0.60 for 1 detection

**0.92**

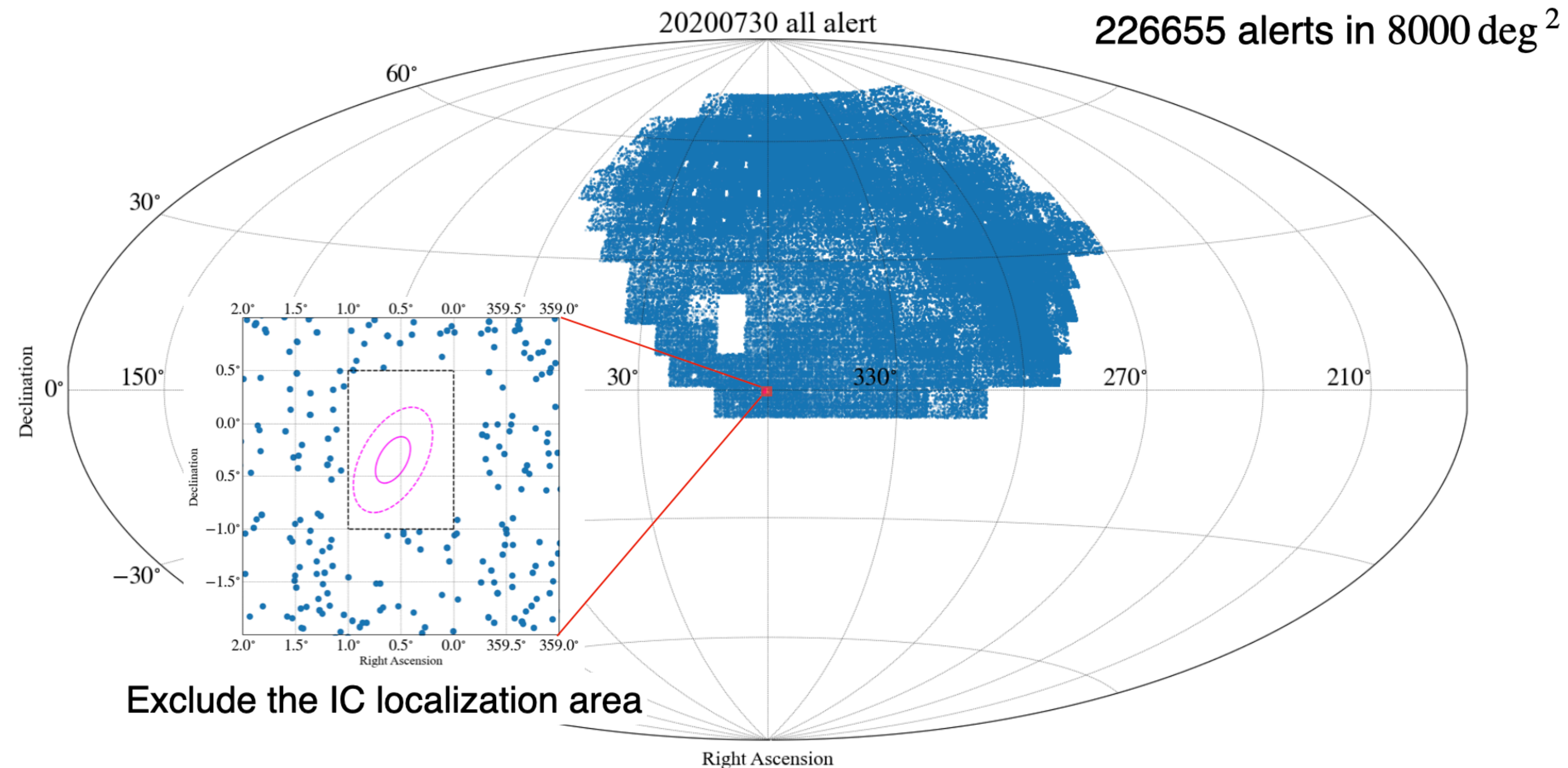
0.93 for 6 detections

**Confirm that new alert stream achieves the benchmark performance**

# IceCube Neutrino Multiplet: optical counterpart search

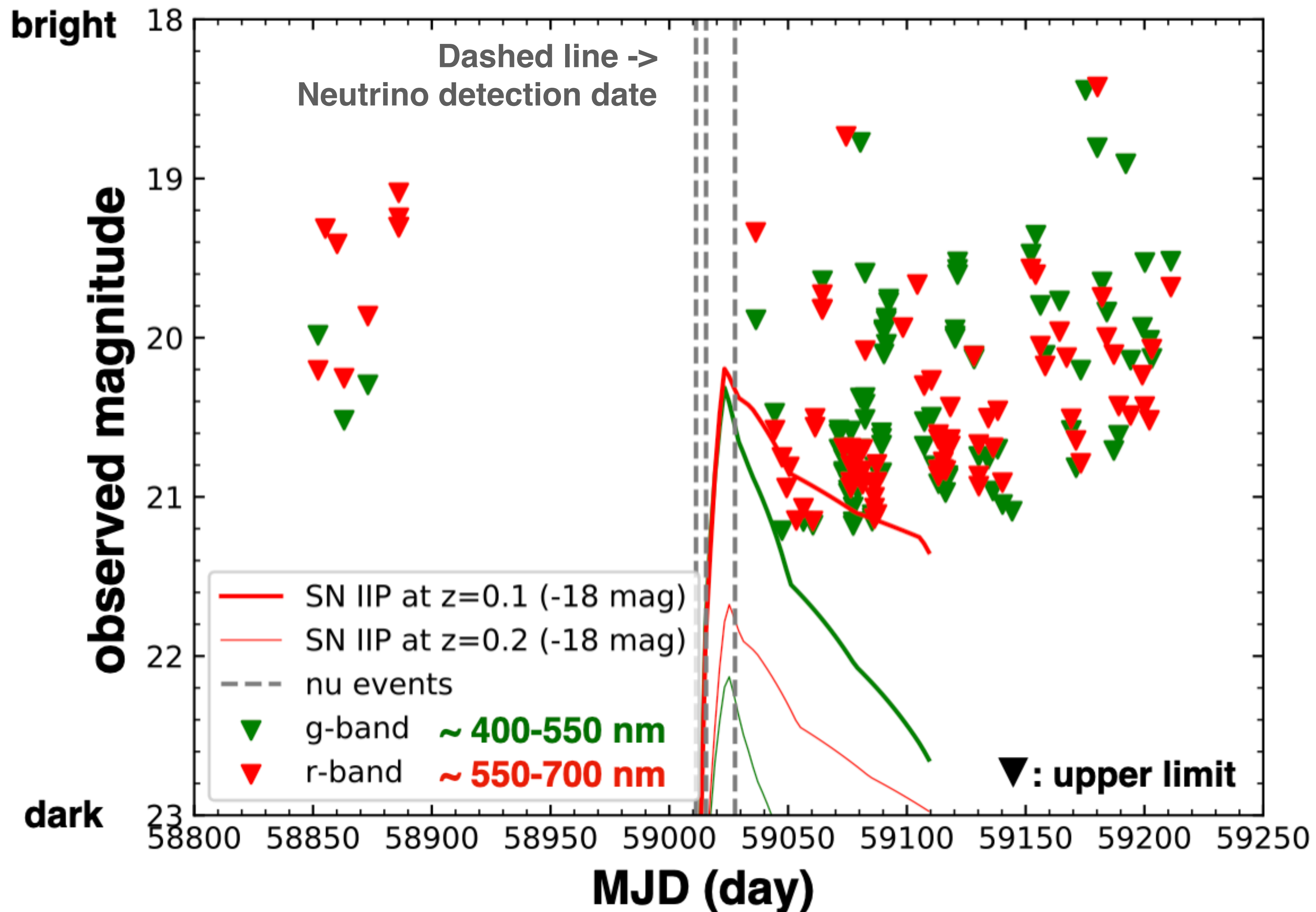
Optical counterpart search system was almost completed with control data

- Low background objects  $\leq 0.03 \text{ deg}^{-2}$  even without distance limit
- TPR was estimated accurately and can be used for estimation of constraint



**We will apply our system to the data in IC localization area. Stay tuned!**

# If no transients are found in the localization area,

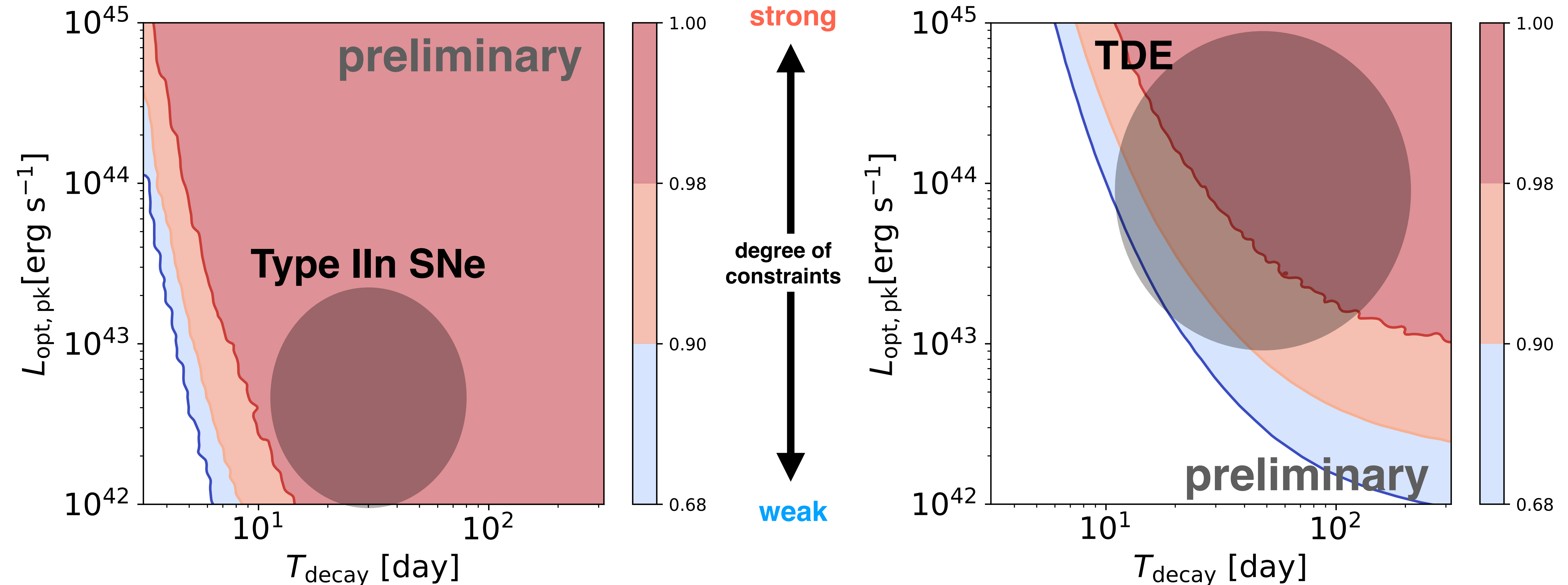


# Demonstration of constraints with ZTF non-detection

made by Kimura Shigeo-san

## Parameter constraints for SNe (Type II<sub>n</sub>)

## Parameter constraints for interacting TDE

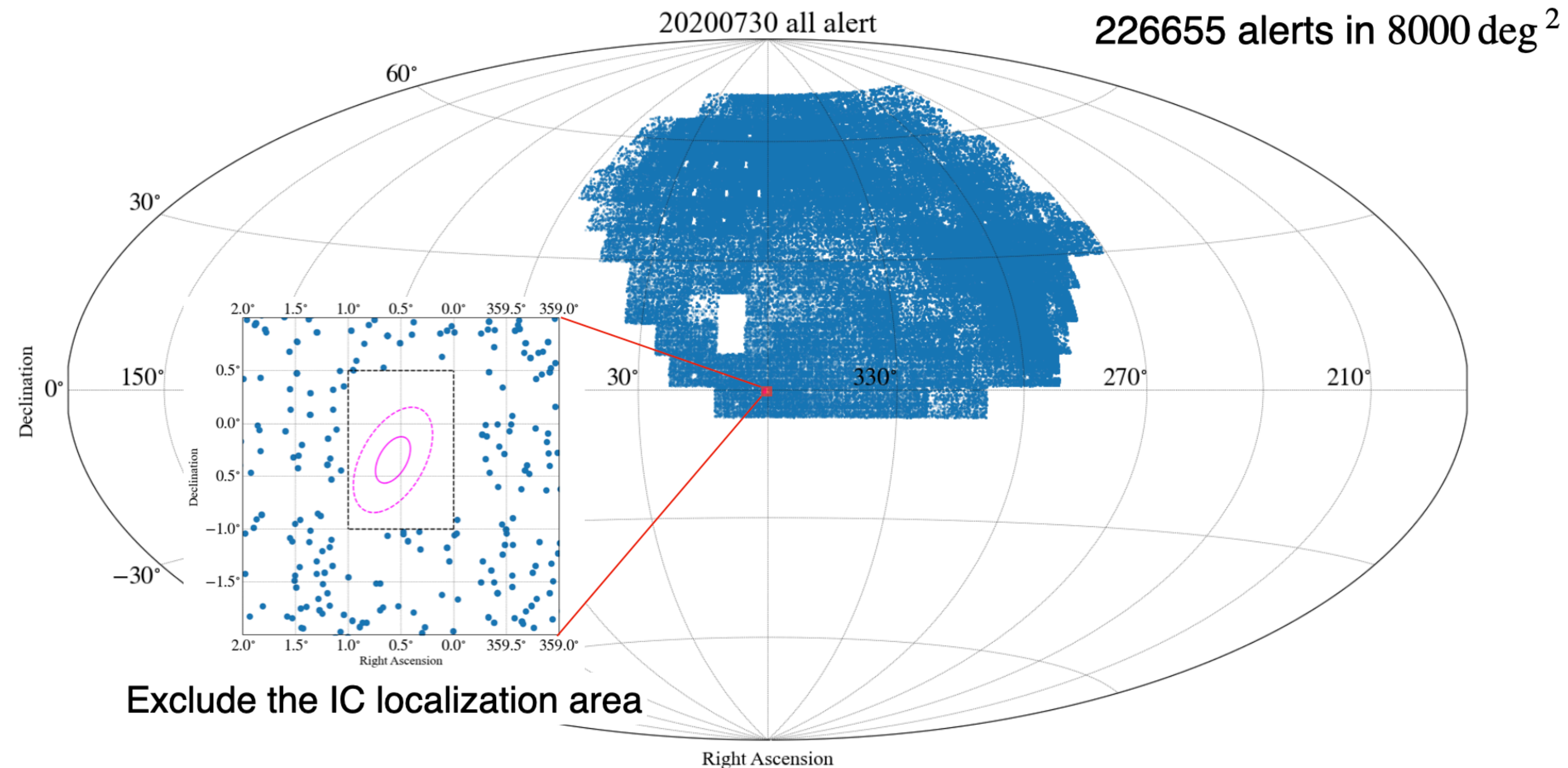


**\*Please note that this assumes non-detection by ZTF team just for demonstration.**

# IceCube Neutrino Multiplet: optical counterpart search

Optical counterpart search system was almost completed with control data

- Low background objects  $\leq 0.03 \text{ deg}^{-2}$  even without distance limit
- TPR was estimated accurately and can be used for estimation of constraint



**We will apply our system to the data in IC localization area. Stay tuned!**