Optical Transient Counterpart Search for IceCube Neutrino Multiplet Events

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0. Overview

- Optical transients with month-long timescales (SNe, TDEs) are possible high-energy neutrino sources.
- Month-timescale neutrino “multiplets” offer a chance to identify optical counterparts in the nearby Universe.
- We perform an archival ZTF search for the optical transient counterpart of an IceCube triplet event.
- No transient candidates are found within the localization region.
- We constrain the properties (peak luminosity and decay timescale) of optical transients as a main source of neutrinos.

Toshikage *et al* 2025
ApJ 993 23

1. Origin of High-energy Neutrinos

Identified high-energy neutrino sources

- AGN with directing jet (TXS 0506+056) IceCube 2018
- Milky way IceCube 2023
- Seyfert galaxy (NGC 1068) IceCube 2022, 2025

Dominant source remains unknown…

Possible optical transient counterparts ?

Supernovae

Image credit: ALMA (ESO/NAOJ/NRAO), K. Maeda et al.

Stein+ 2025 (Type Ibn SNe),
Lu+ 2025 (Type IIn SNe)

Tidal disruption events

Image credit: M. Garlick/SPL/Corbis

Stein+ 2021, Reusch+ 2022,
Jiang+ 2023 (MIR), van Velzen+ 2024,
Yuan+ 2024, Li+ 2024 (X-ray)

2. Challenges in Optical Follow-ups

Image credit: NAOJ

Detectability : ○

Background rate : ×

Image credit: ZTF/Caltech

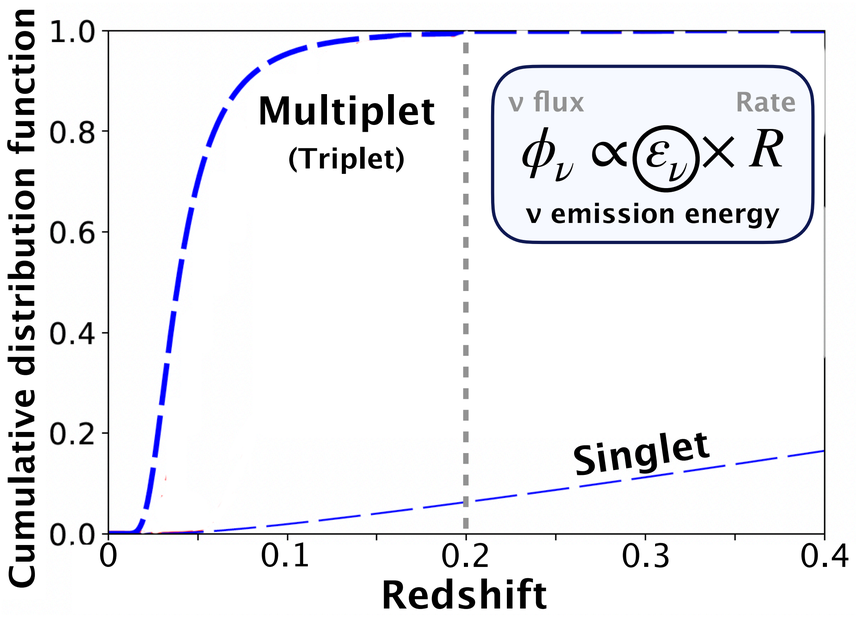
Detectability : ×

Background rate : ○

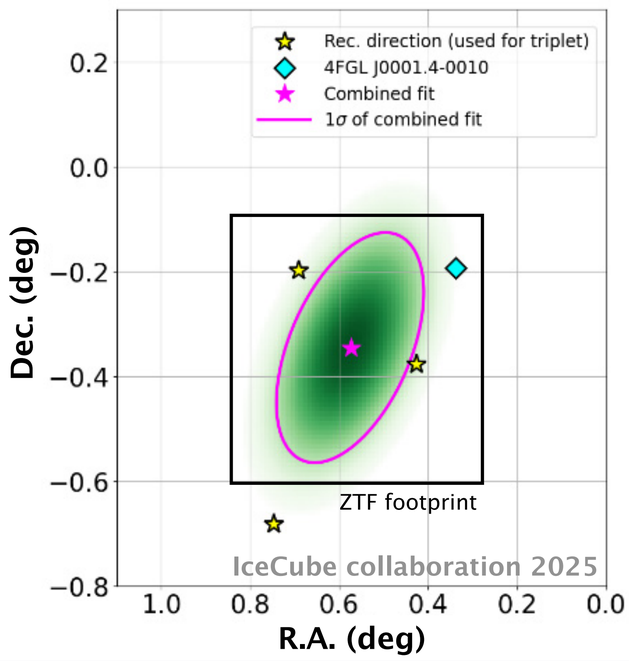
3. The First Counterpart Search for a Month-timescale “Multiplet” Event

“Multiplet” : Multiple neutrino detections
IceCube is sensitive to nearby multiplet event

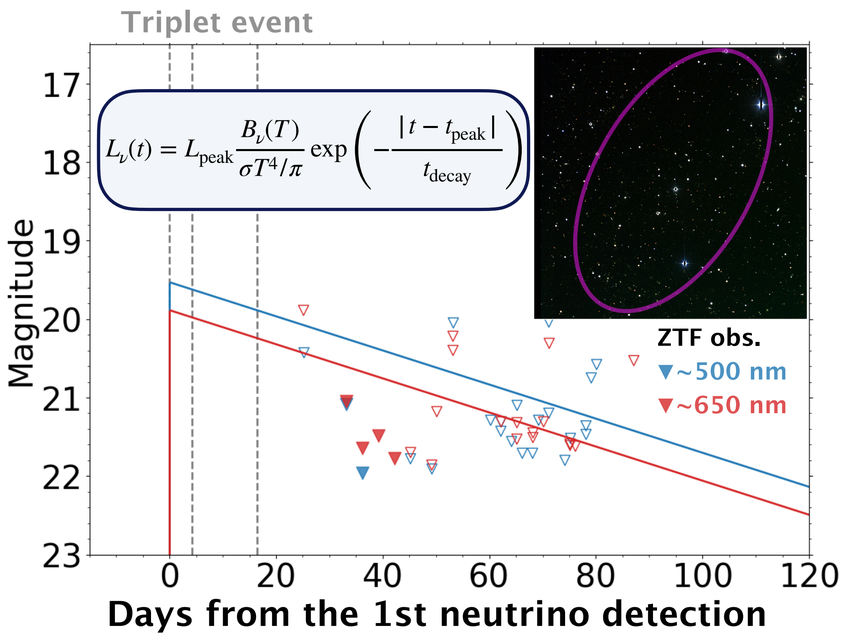
Yoshida et al. 2022



Triplet (triple neutrino detections)
within 16 days in June 2020!

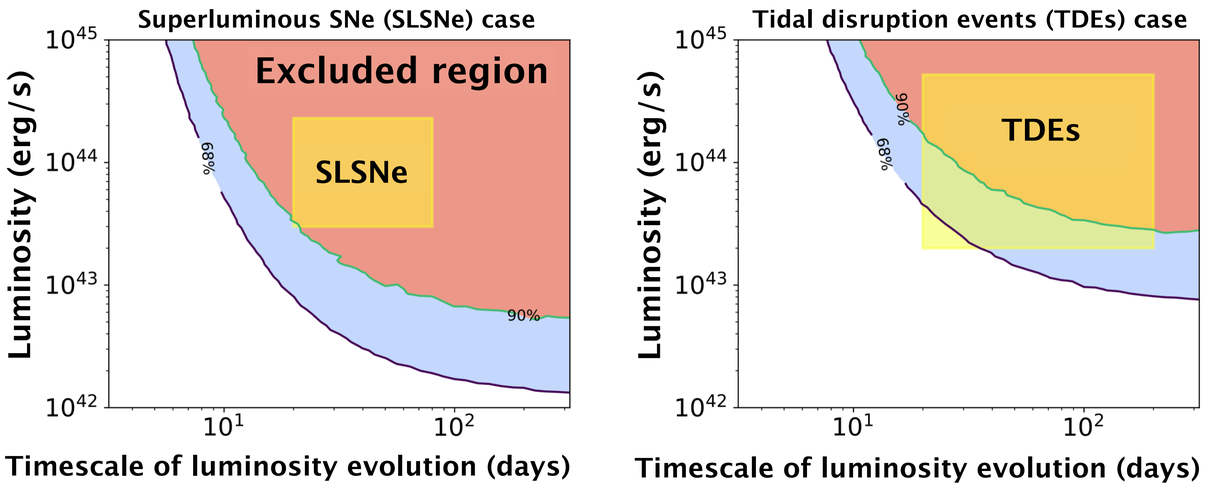


Optical data from ZTF + dedicated analysis
= high detectability&low background rate



4. Constraints on properties of transients

No candidates in the IceCube triplet direction
→ Constraints on optical transients as main neutrino sources



※Signalness (Astrophysical probabilities of this event) ~ 50 %
We continue performing the same analysis for future multiplets

5. Future Prospects: Real-time Follow-up

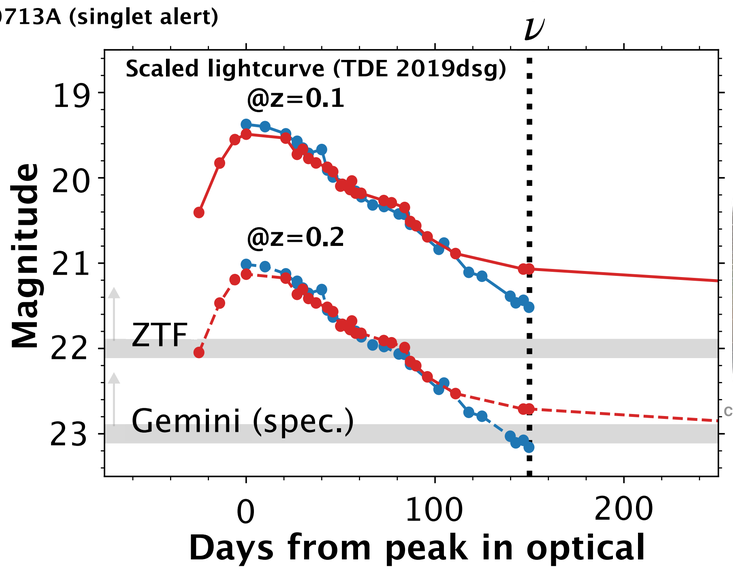
Wide field photometry → Deep spectroscopy

Test observations with Kiso/Tomo-e has been done for IC250713A (singlet alert)

A Proposal to Gemini has been submitted

Image credit: KOJI OKUMURA

Image credit: ZTF/Caltech



Credit: International Gemini Observatory

Identify/Constrain optical transients as high-energy ν sources
+ Spectroscopic observations to probe the ν emission environment