VHE gamma follow-up programs of HE neutrino alerts

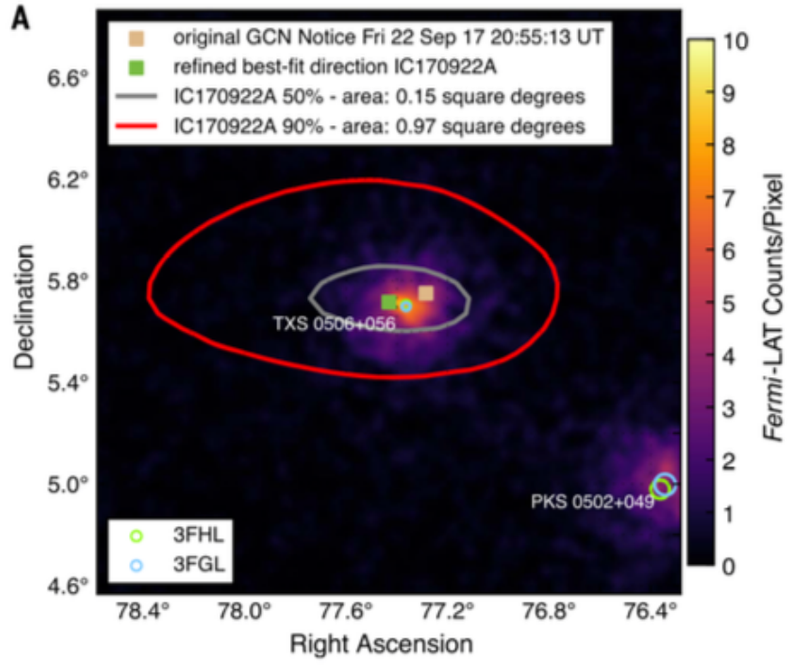
Koji Noda (Chiba U.),
Manuel Artero (IFAE), and Armand Fiasson (LAPP/ILANCE)
on behalf of the CTA LST project

29 Mar 2023
International Conference on the Physics of the Two Infinities @ Kyoto

Introduction

- Long-standing "natural" suggestions to try to detect both HE ν and VHE γ from the same type of sources
  - as π's from pp / pγ emits γ if π0 while ν if π+/-
- ν source hunting with VHE γ since 2012, **before** the discovery of astrophysical ν in 2013 by IceCube
- IceCube alert channels (no follow up for other HE ν exp. now)

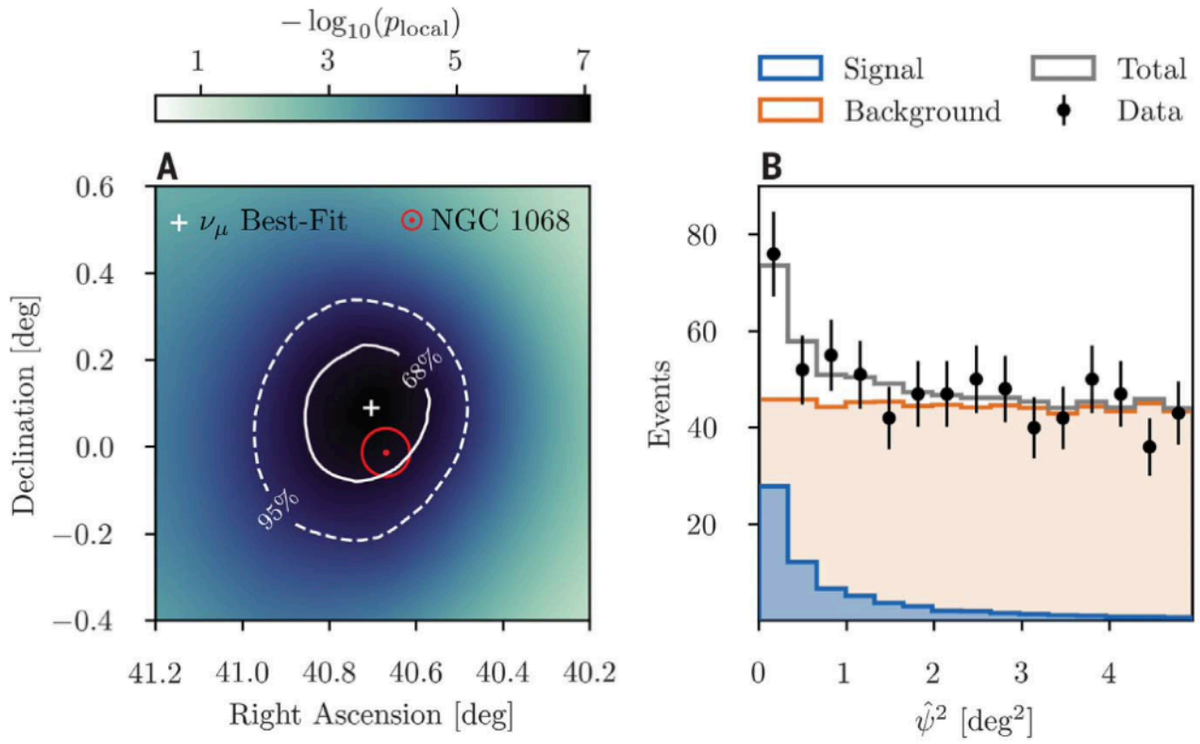
1. Gamma Follow Up (GFU) program of IceCube events
   - **Multiple events in a time window of s - 180 d, correlated with known γ-emitters, private alert**
2. Single track events
   - **HESE/EHE => GOLD/BRONZE, open alerts**
   - **EHE IC170922A triggered TXS 0506+056 obs.**
3. Multiplet all-sky
   - **No correlation taken, ~0.5 / yr**
4. Cascade
   - **Large error (3-30 deg), difficult to follow up**



IceCube Coll., Science (2018)

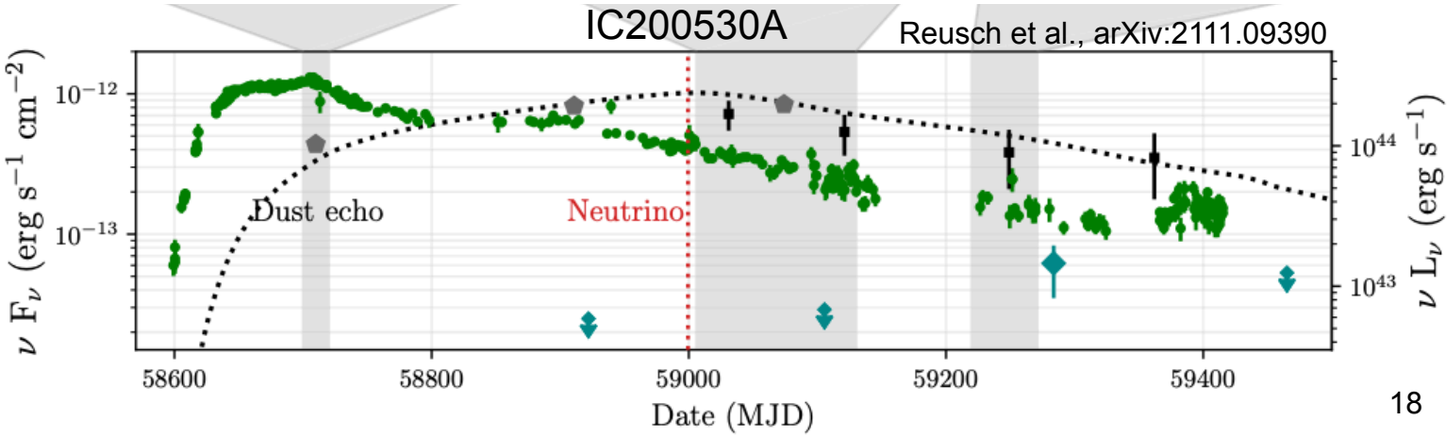
Non-blazar ν/γ sources?

- 2nd HE ν source: NGC 1068
  - Seyfert galaxy (**not blazar**)
  - Detected by Fermi (**not in VHE**)
  - Observed independently by MAGIC (**not under neutrino followup**)
    => Very weak in γ, mostly steady?
    Much different from TXS 0506
  - Strong constraint set by MAGIC, a cutoff around GeV?
    - Possibly, e.g., both pp and pγ contribute and the dominant process depends on particles, λ, or even vs. time?...

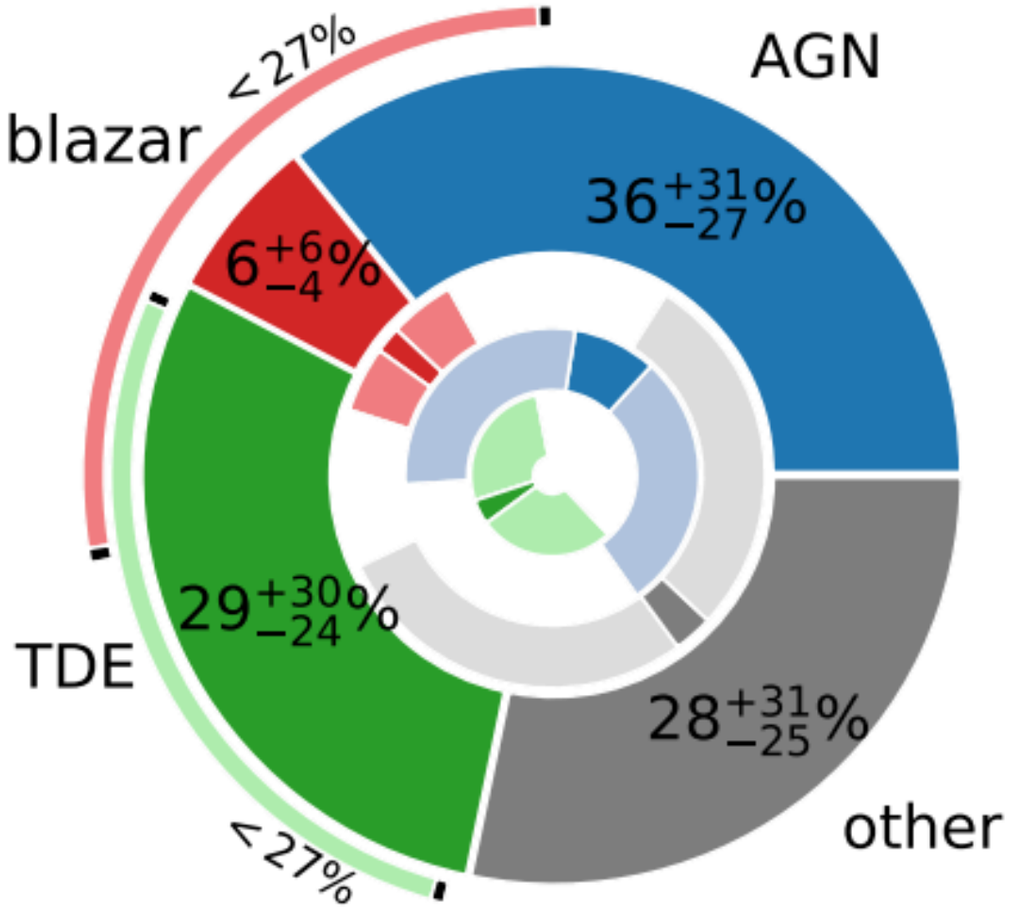


IceCube Coll., Science, **378**, 538-543 (2022)

- 3 TDEs in 2019-2020 found spatially coincident with ν, temporally with an IR flare
  - not (yet) observed in VHE γ



New targets of Gamma Follow Up?



Bartos et al., arXiv 2105.03792

- Fractions of the diffuse flux explained by each source types
  - Large uncertainty due to small statistics: 1 for non-blazar AGN (NGC 1068), 1 for TDE (191001A) in this calculation
- "The known γ-emitters are NOT the majority of the ν-emitters"...

  What can be done still with IACTs?
  - Need a higher precision for non-blazar AGN and TDE
  - Need more statistics for both

- **Need to follow up ν with "less bias (if not zero)" to γ-emitters**
  - In parallel to the existing programs for blazars, GRBs, Galactic srcs,,,

IACTs and CTA LST status

MAGIC

CTA LST

- Current gen. IACTs operational since 2000's

  MAGIC & VERITAS in GFU since ~**2012**, H.E.S.S. since ~2015
- Next gen. Cherenkov Telescope Array (CTA) since ~2020, only with one Large Size Telescope (LST)
  - LST1 is officially a prototype, and LST1 data are all under LST team but not CTAO
  - 3 more LSTs will be built by 2025. Observations will follow by the LST team until the official telescope acceptance by CTAO (which would take time)
- In **2022** LST & IceCube signed an MoU

  Ready for something new already, after ~10 years of GFU history

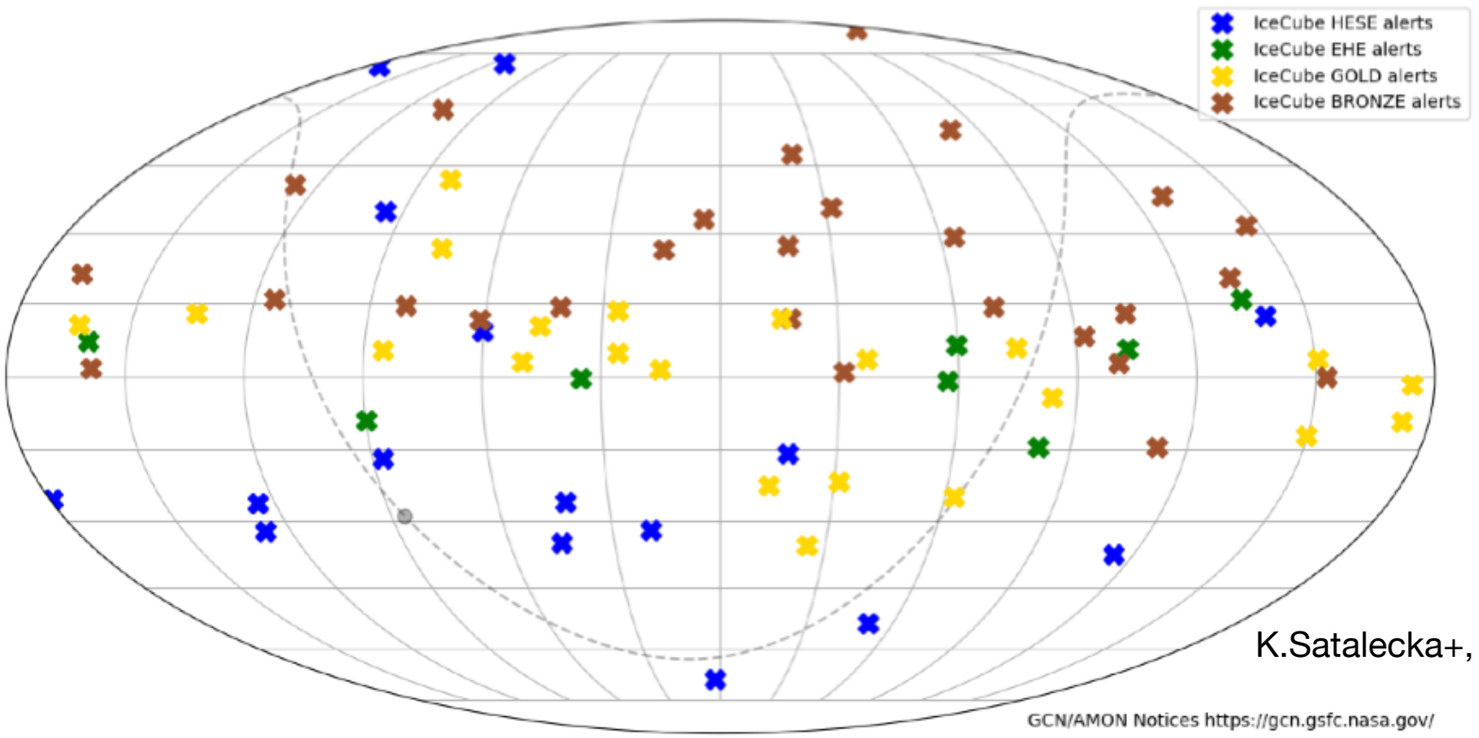
LST strategies 1&2

1. Gamma Follow Up (GFU) program
   - **Multiple events in a time window of s - 180 d, correlated with known γ-emitters, private alert**

2. Single track events
   - **HESE/EHE => GOLD/BRONZE, open alerts**
   - **EHE IC170922A triggered TXS 0506+056 obs.**

Need to revise the list of known γ-emitters and reduce the rate to allow longer obs for each alert

Fine as it is, to catch events like TXS 0506+056 (or to confirm that TXS is rare)
Bronze are mostly from north, good for LST in LP



K.Satalecka+, PoS(ICRC2021)960

LST strategies 3&4

3.Multiplet all-sky

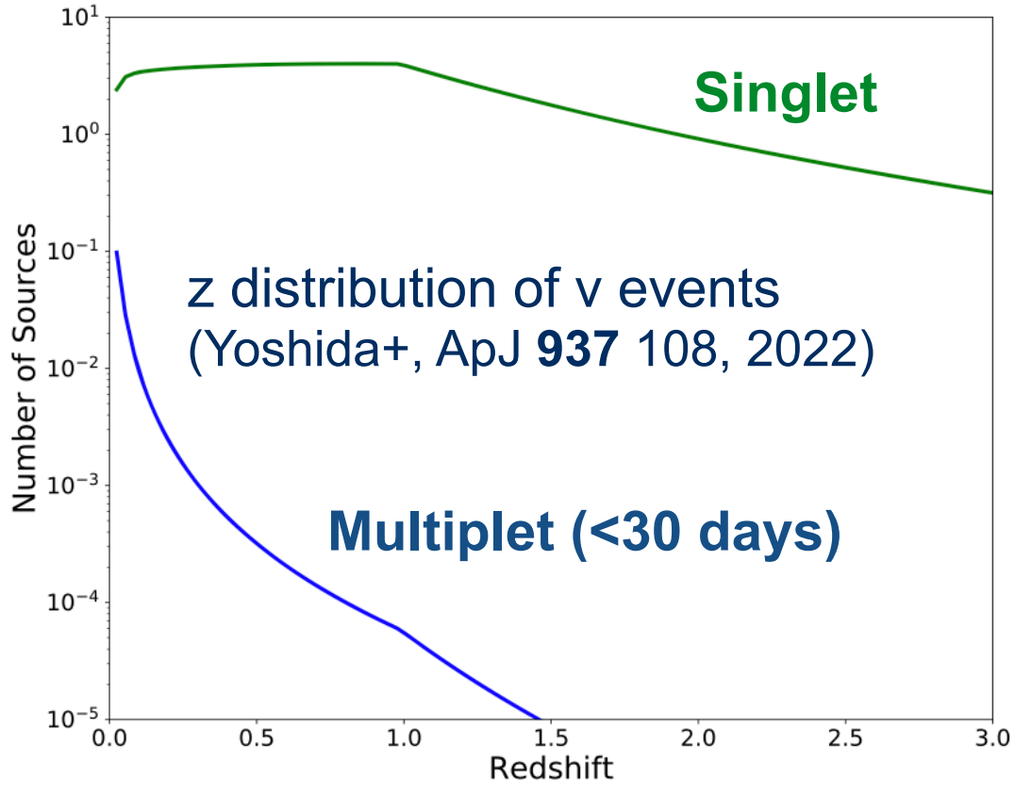
– **No correlation taken, ~0.5 / yr**

4.Cascade

– **Large error (3-30 deg), difficult to follow up**

Would like to receive more alerts not gamma-biased

Similarity to GW followup
Collaborative work will be expected in the coming O4



Multiplet is by construction from nearby sources, good for IACTs suffering from EBL

We should observe such alerts even without any blazar found around them

Details of the list revision (1.)

- Current criteria (from K.Satalecka+, PoS(ICRC2021)960)
  - Fermi-LAT catalogs

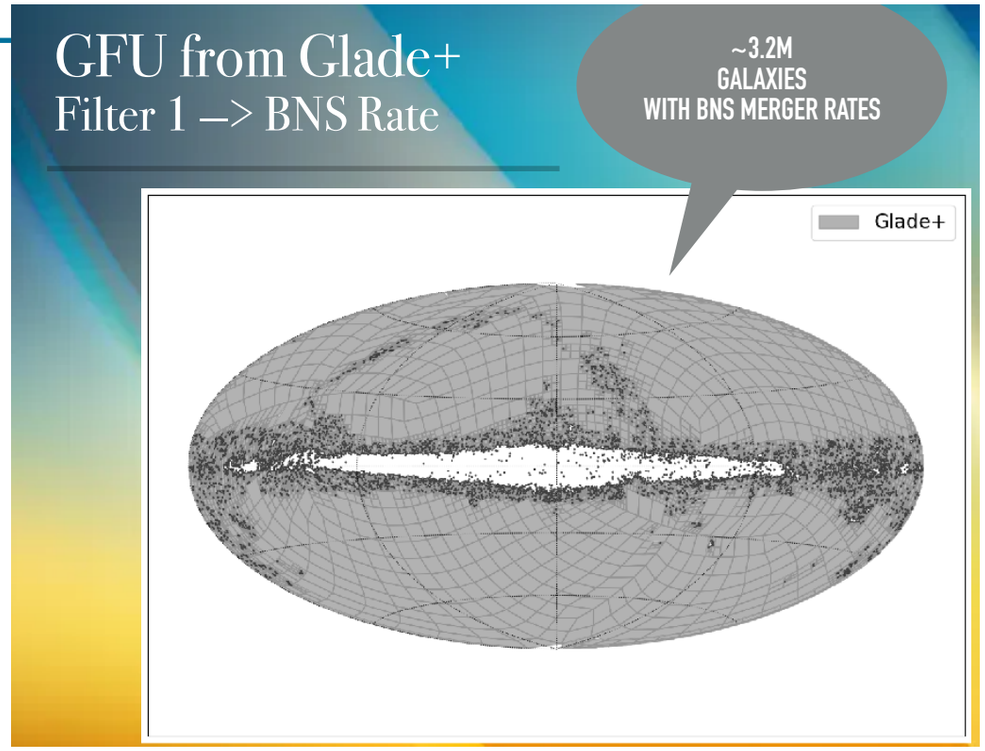
    - Extragalactic source with known redshift and $z \leq 1.0$
    - 3FGL: variability index > 77.2; 3FHL: variability based on Bayesian blocks > 1
    - Culmination at the IACT site within a chosen zenith angle limit (usually <45°)
    - Assuming that the source can produce a gamma-ray flare with a 10-fold increase over the average *Fermi*-LAT flux, the extrapolated flux above 100GeV has to exceed the IACT 5σ sensitivity for observation times between 2.5 h to 5 h.

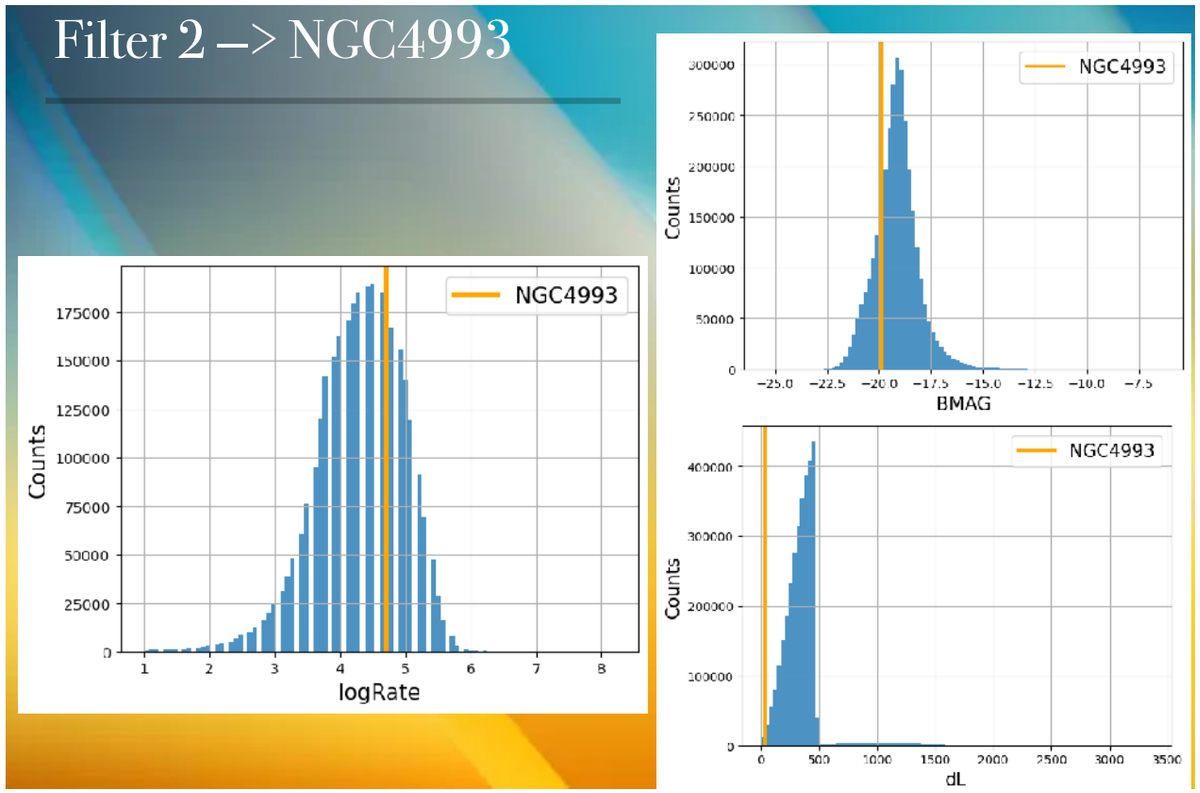
    - 4FGL is available now
    - 2 arbitrary cuts by **variability** and **flux** => *remove the variability cut and tune the total number only with the flux enhancement factor*
    - No EBL attenuation taken into account => *introduced before the cuts*
      - without known redshift: cut them, or assume redshift
  - TeVCat (TeV gamma source catalog http://tevcat.uchicago.edu/) "all extragalactic sources detected by IACTs,,, added"
    - but without **when & how.** TeVCat is updated regularly without notice => *Need clearer description (at least)*

Trial of non-biased list (3.)

- "Correlation with nearby galaxies, instead of gamma sources?"
- Galaxies catalog GLADE+
  - **3.2M** with the BNS entry
- Small distance is not enough to get a reasonable number. Used BNS rate & Bmag to select those with a high BNS probability
  - Cut by NGC 4993 (host of GW170817 event, 44 Mpc)

=> 224 galaxies, **94** by visibility
=> **73** by removing one of two too-close galaxies in the sky





Revised list for LST

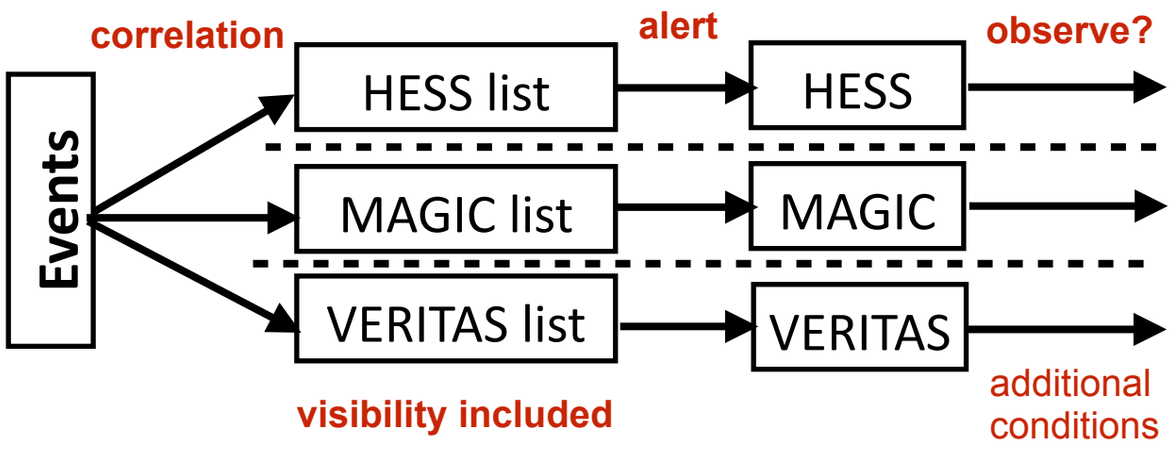
- Fermi: 163 (MAGIC) => **110** (cutting all without redshift)
  => 152 (+ extragalactic with z=0.3 assumed)
- TeVCat: 15 (MAGIC) => **29** (52 extragalactic (after - duplications)
  - GRBs, unIDs, remained SNR/PWN)
- Unbiased: 0 (MAGIC) => **73**
- Total: 178 (MAGIC) => **139 γ sources, 73 galaxies. 212 in total**

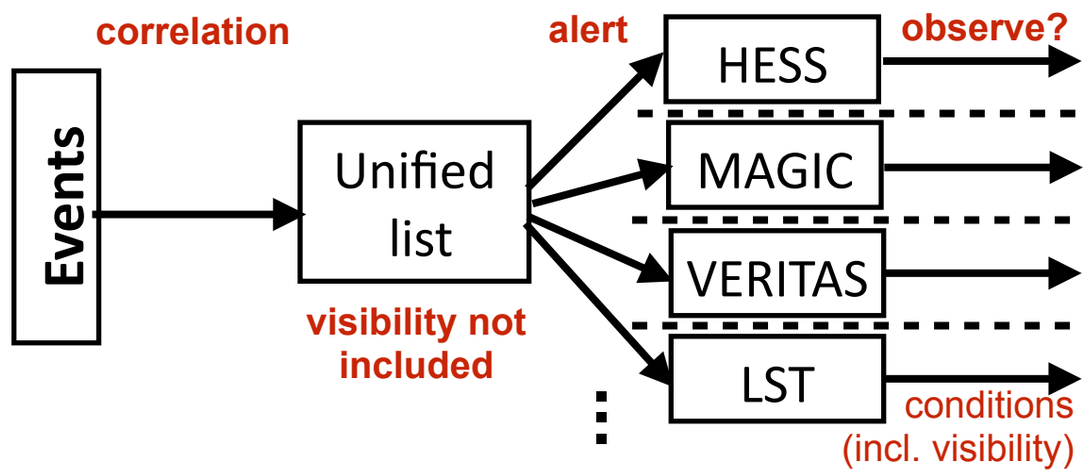
Discussions (before talking to IceCube)

- Rate of ~1/month will be +20%, which is practically acceptable, but the observation time per source will not change, even be reduced...
  - With 42 without z, GFU alone unchanged (178 => 181)
- Too many with +73 galaxies, but the galaxy list is already cutting much
  - Expected to be dim in VHE γ, need to observe them longer...

Discussions with IceCube

- Any strategy will/should be agreed with IceCube anyway, so we started to contact and discuss with IceCube
- **Disclaimer: nothing IceCube-official here**
  - **Unification among IACTs**: 1 γ-source list per IACT, and alerts are sent separately, but in fact most alerts are to multiple teams at once due to overlaps. A unified list allows a smoother flow & flexibility (dep. teams)
  - MoU matters, but doable and worth trying





  - **Non-gamma multiplet channel:** Activities existing for a multiplet alert without any correlation with sources. A list of (<several) nearby galaxies can be "attached" in the alert. IACTs can decide if/how to observe.
  - **Public?**: both will be preferably public finally, for easier paper publishing

Summary

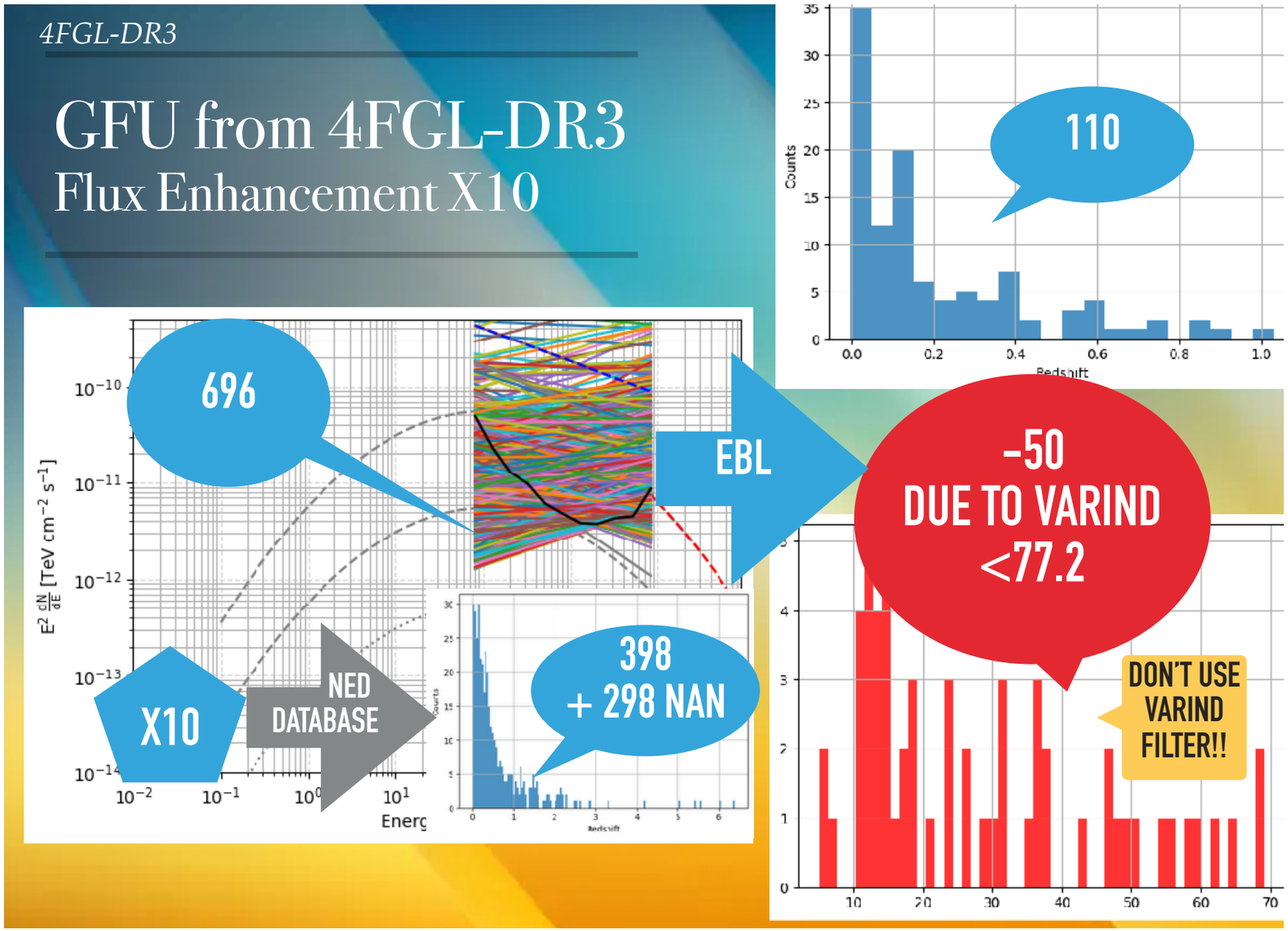
- Mystery of high energy ν sources is still there,
  but the suggested strong ν-γ connection is not there
- Need to revise the gamma-followup strategy
- CTA LST started scientific operation, and is ready for new trials to solve the mystery
- First proposals to reduce the bias to gamma-sources and to add a new program to observe nearby galaxies
- The proposals are sent to IceCube
  Started discussions under a dedicated MoU
- Improvements to be implemented in a year scale, still before the second LST is operational

Comments / suggestions are welcome!

backup

4FGL: Flux with EBL

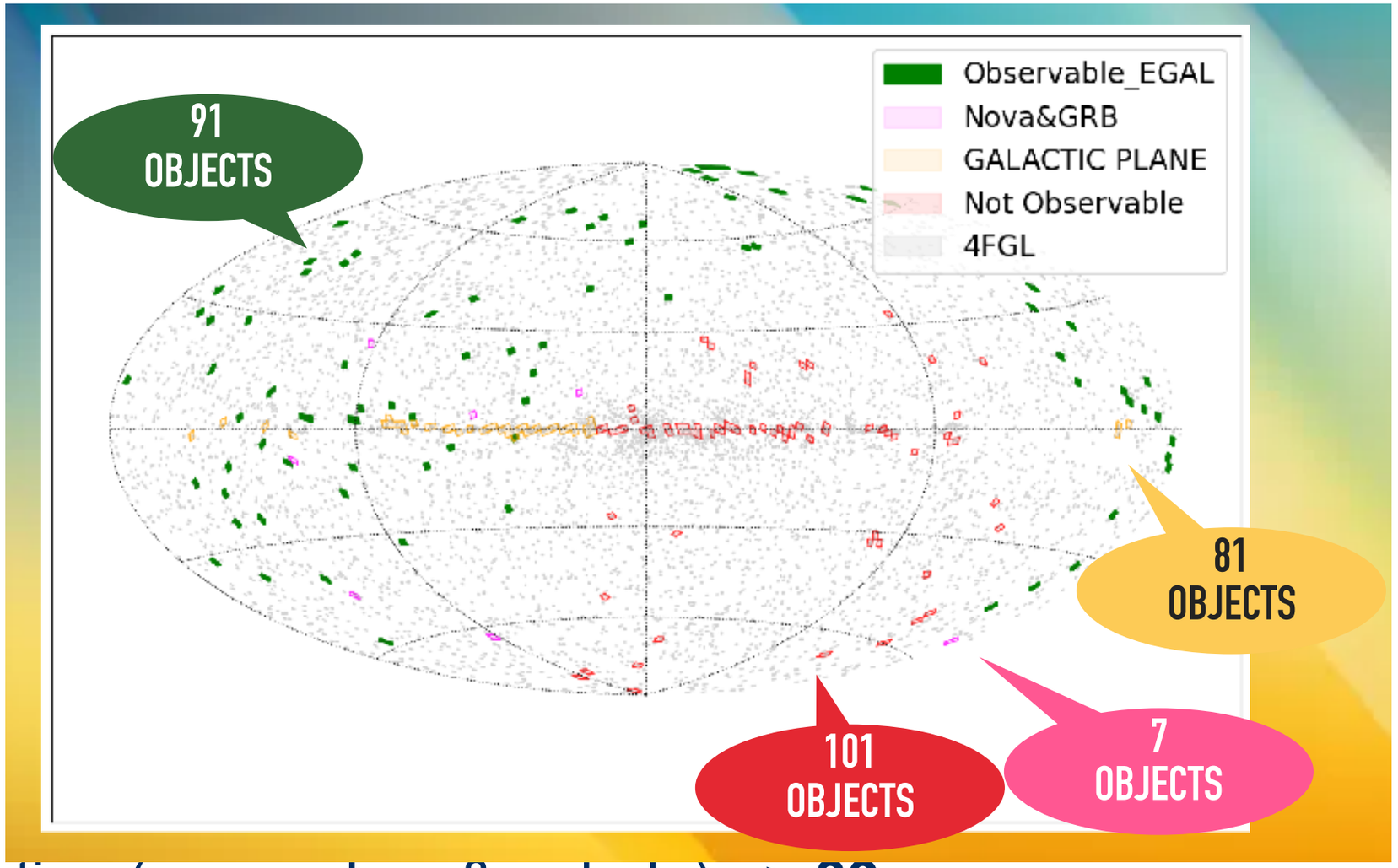
- Flux: extrapolation with PL to VHE range, and flux enhanced by x10
- Compared with IACT sensitivity
  => **696** survived
  => **398** known z
- EBL attenuated, compared again with the sensitivity
  => **110 in the end**
  - Tried flux x1, x2, x5, but the same x10 is the optimal
  - No need for z<1



- ***Fully cutting sources without z, which are probably far γ emitters***
- ***Variability is not used any more***

Adding TeVCat sources

- **280** in the original (as of Oct 2022. TeVCat is updated very frequently!) => **179** by visibility => **98** extragalactic (|b| >2.5 deg)
- -7 non-repeating transients (GRB and Nova) => **91**
- -46 double-counts with 4FGL, -6 duplication (e.g., pulsar & nebula) => **39**
- Finally removed (by hand) unIDs, galactic SNR/PWN => **29**

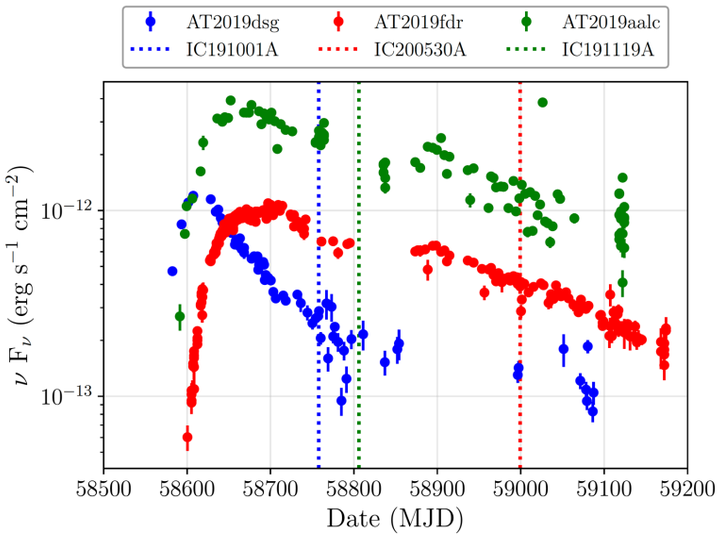


LST proposal for γ emitters 110+29 = 139

reduced from MAGIC 163+15 = 178

TDE: Dust echo

(by W. Winter)



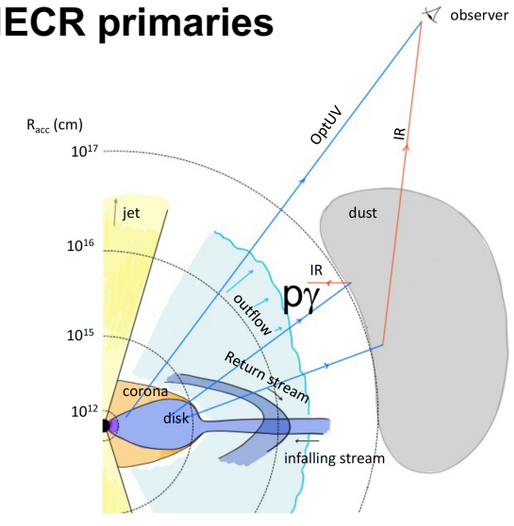
Simeon Reusch @ ECRS 2022

Common features

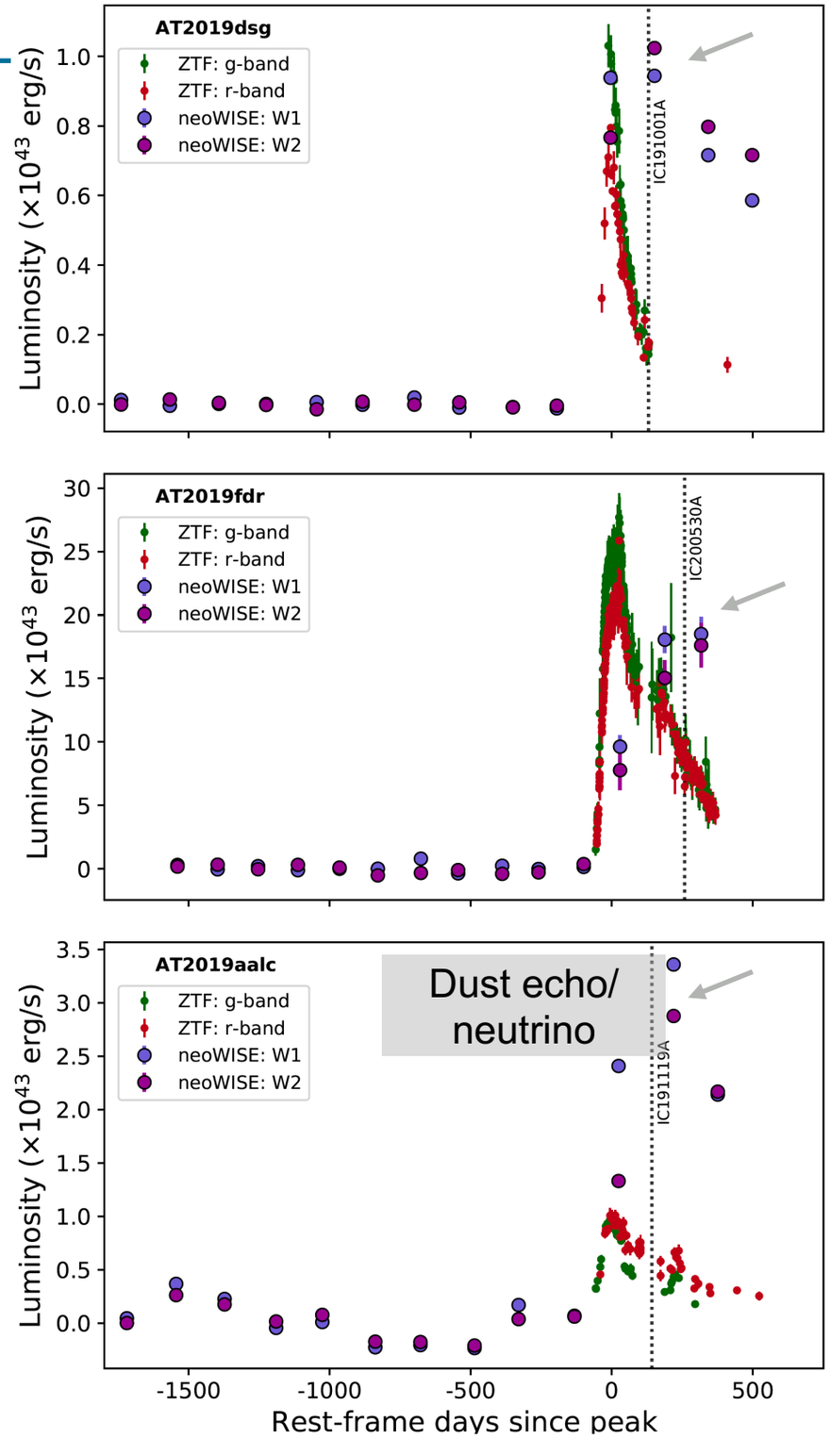
- Delayed neutrino signal
- Delayed strong dust echoes in the IR range
- High black body luminosities
- X-ray detections

Dust echo – UHECR connection?

- Third TDE found through strong dust echo commonality; 3.7σ overall
  van Velzen et al, arXiv:2111.09391
- Dust echo correlates with neutrino → time delay in all cases.
  Target for pγ neutrino production?
- Photon energy (infrared) points towards **UHECR primaries**



Is the dust echo connection a **smoking gun signature for the acceleration of UHECRs** in TDEs?



van Velzen et al, arXiv:2111.09391