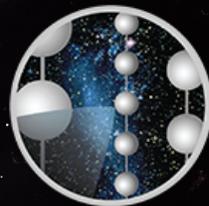


Search for High-Energy Neutrinos from TDE-like Flares with IceCube

Jannis Necker
for the IceCube Collaboration

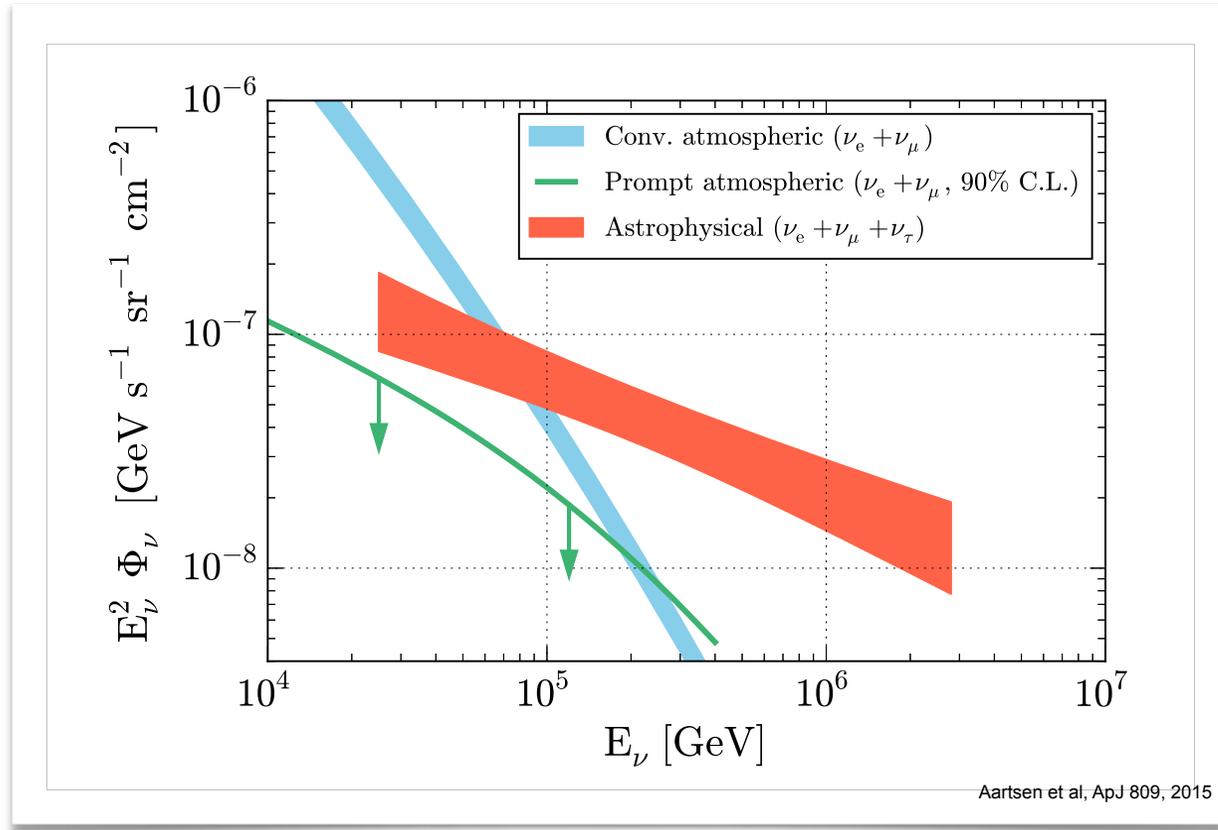
HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES



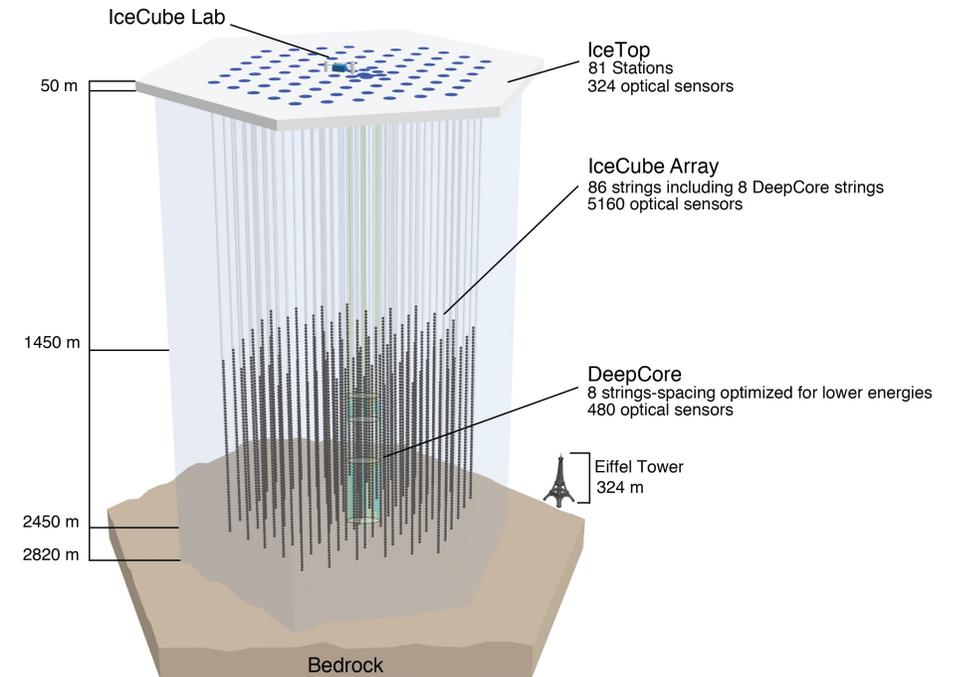
ICECUBE



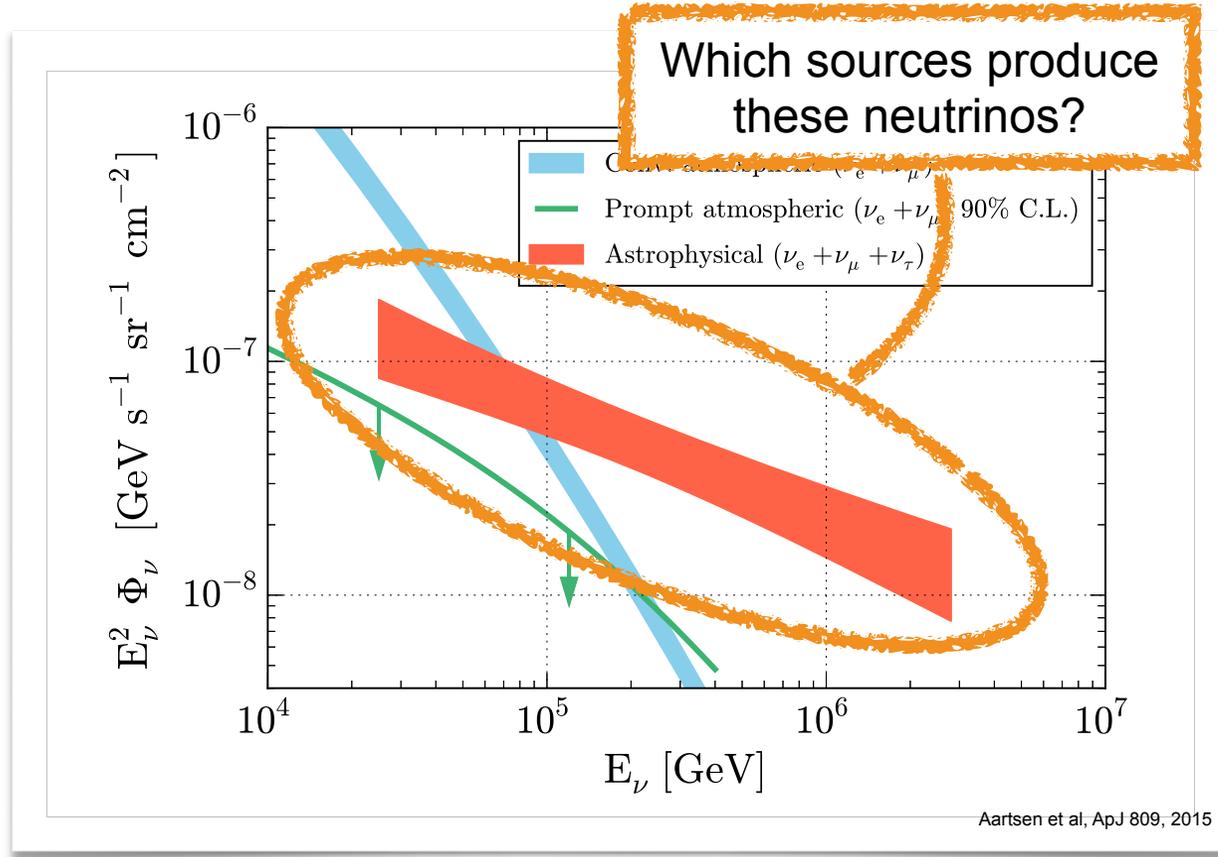
The IceCube Neutrino Observatory



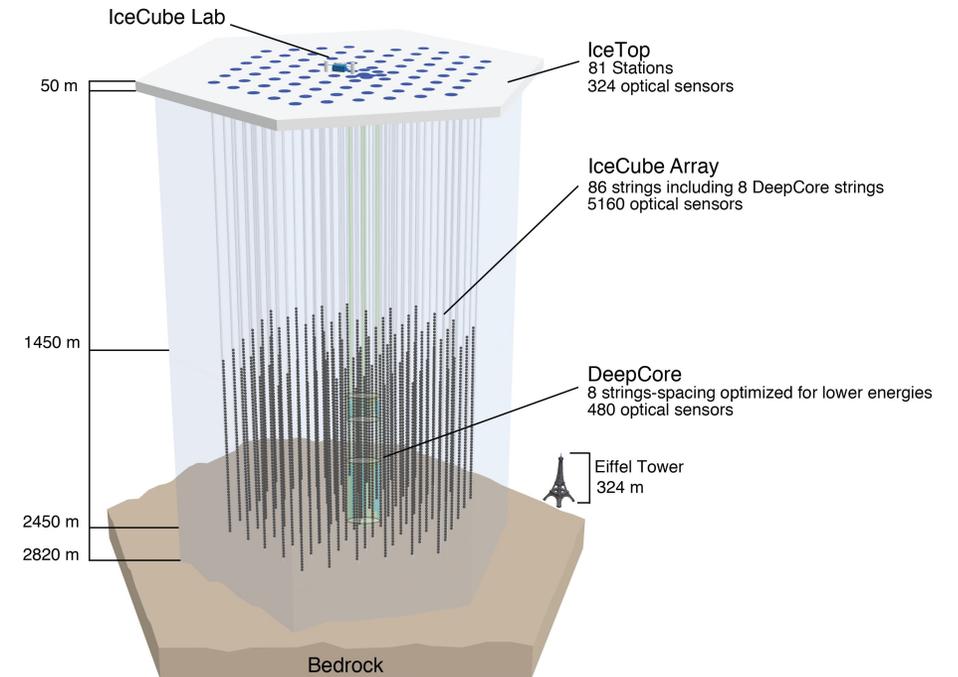
- km³-scale **neutrino detector** array in the antarctic ice
- Detecting Cherenkov light of secondary through going charged particles → reconstruction of interacting neutrino
- **Significant excess at high energies** interpreted as astrophysical neutrino flux



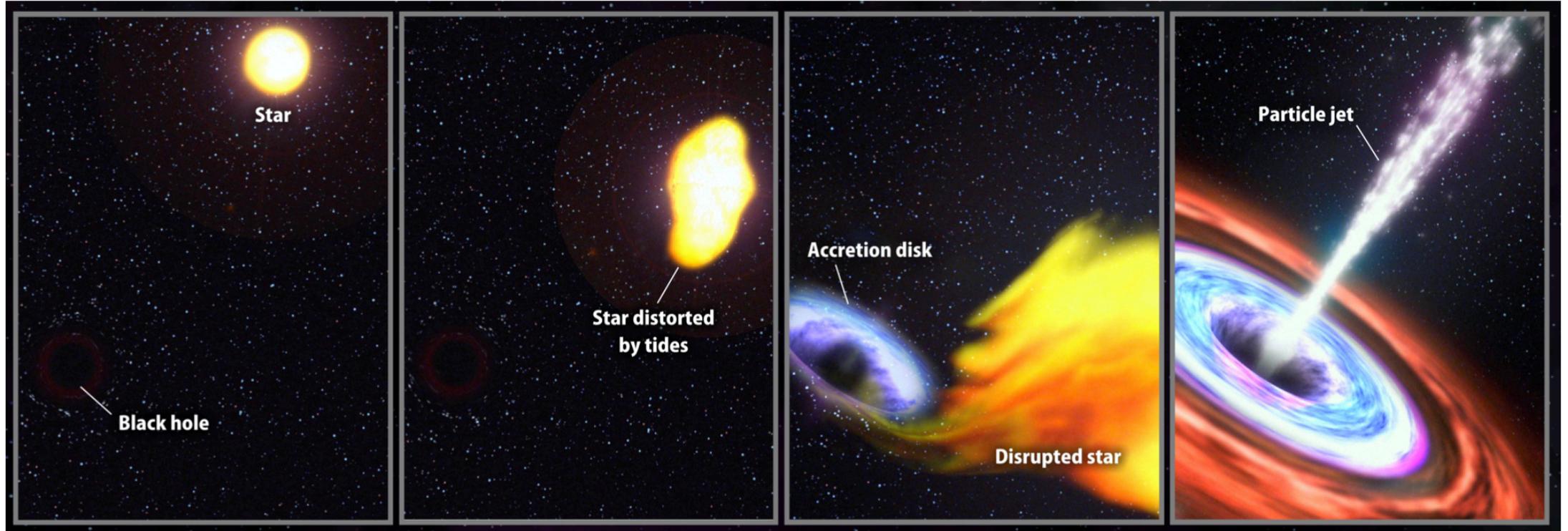
The IceCube Neutrino Observatory



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Tidal Disruption Events (TDEs)



Credit: NASA

1

2

3

4

Tidal Disruption Events (TDEs)

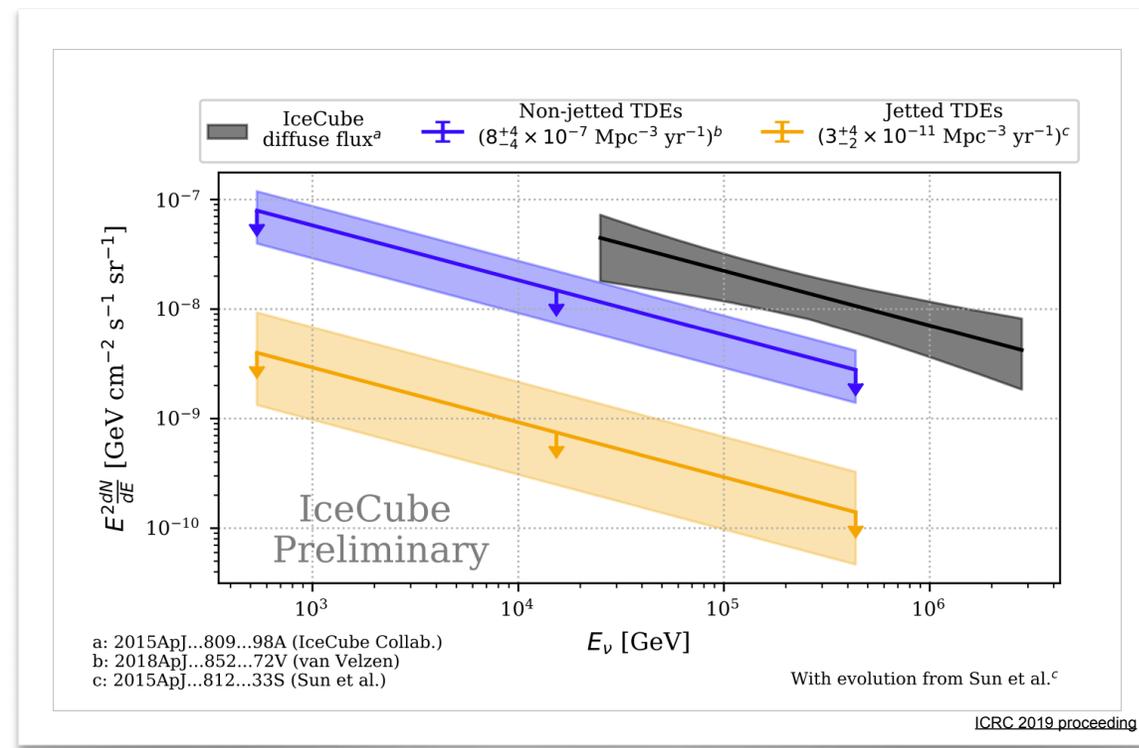
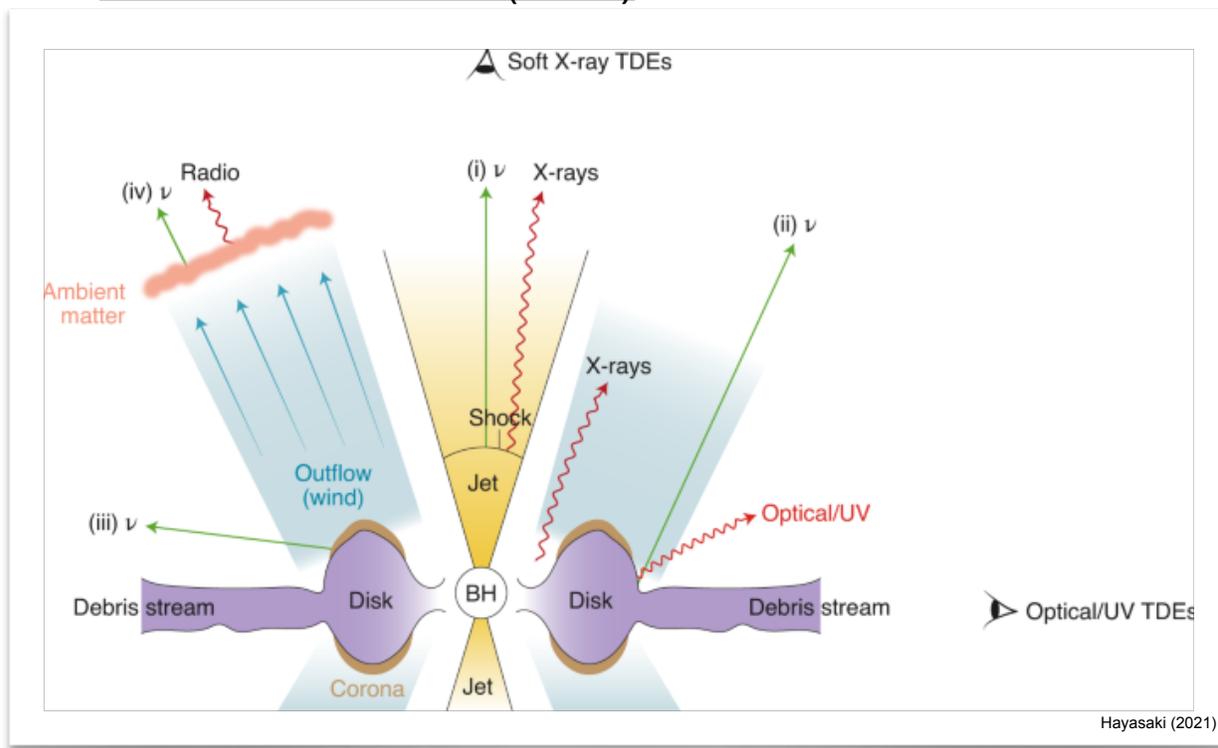
The Neutrino Connection

TDEs suggested as sources of high-energy neutrino emission

- [Dai & Fang \(2017\)](#)
- [Hayasaki & Yamasaki \(2019\)](#)
- [Lunardini & Winter \(2017\)](#)

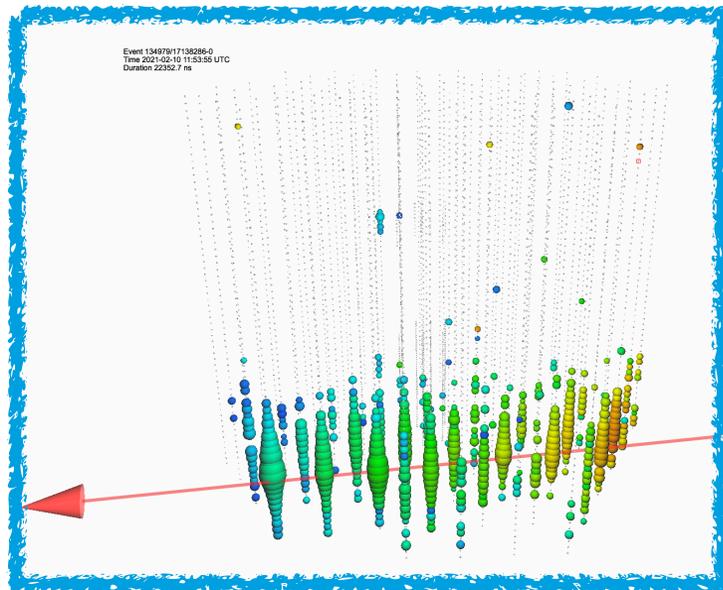
TDE Stacking analysis by Robert Stein

- stacking of 53 TDEs (2018)
- result: upper limits



Optical Follow-up of High-Energy Neutrinos

IceCube detection of **neutrino with high probability of being astrophysical**



Real-time GCN alert

Optical observation with the Zwicky Transient Facility (ZTF)



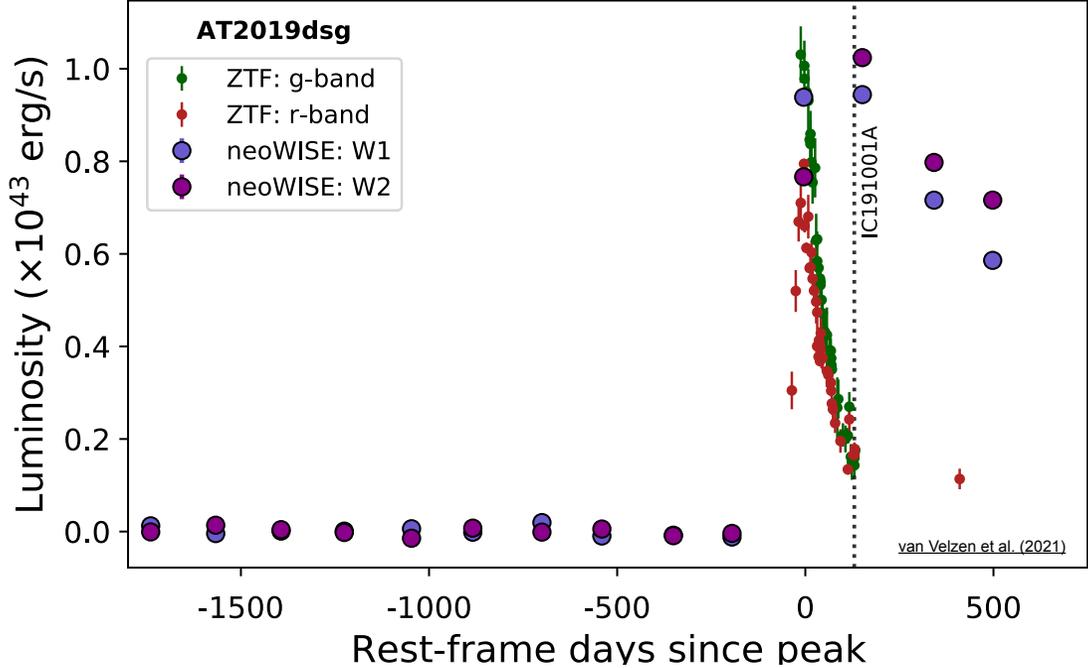
see talk by R. Stein (Thursday, 15:00)

Optical Follow-up of High-Energy Neutrinos

Two Coincident (candidate) TDEs

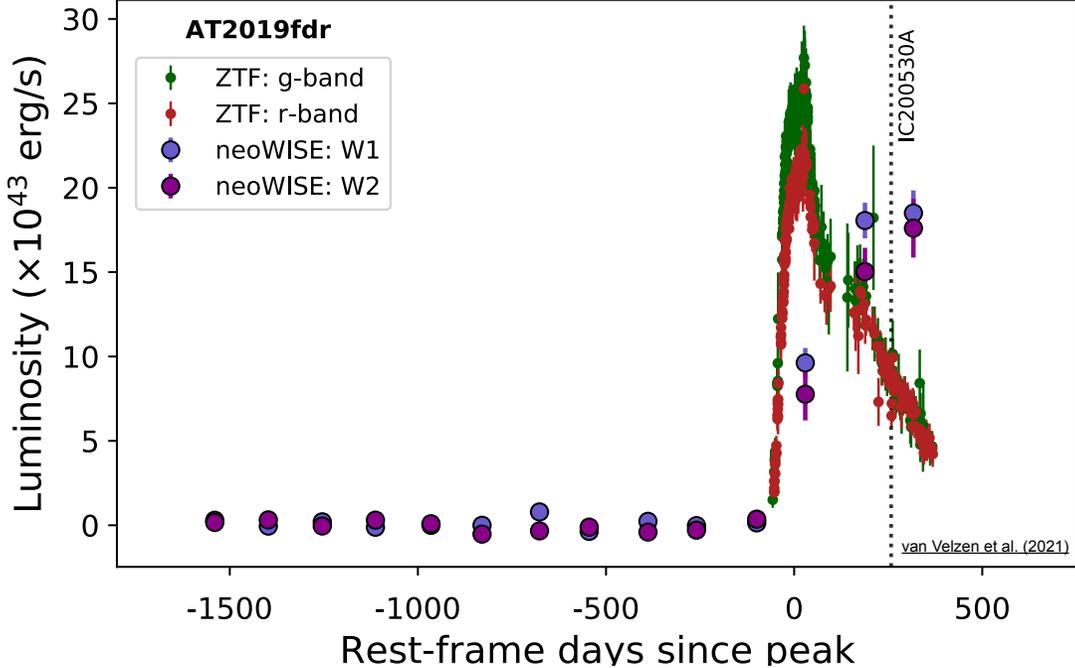
AT 2019dsg + IC191001A

Stein et al. (2021)



AT 2019fdr + IC200530A

Reusch et al. (2021)



chance-coincidence: 3.4×10^{-4}

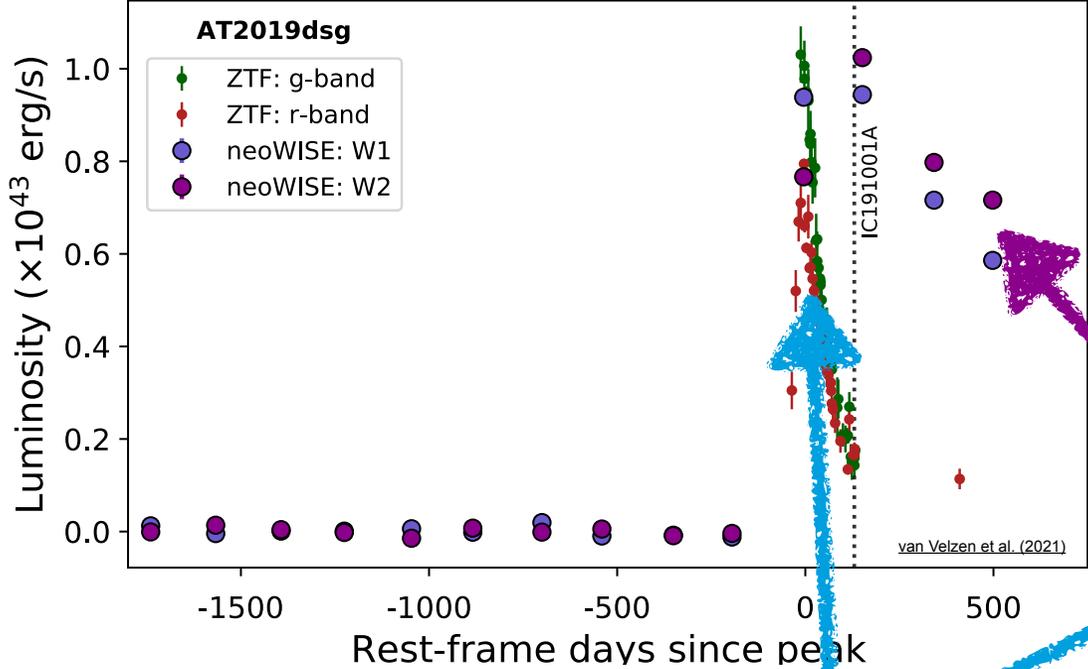
(Reusch et al. (2021))

Optical Follow-up of High-Energy Neutrinos

Two Coincident (candidate) TDEs with dust echos

AT 2019dsg + IC191001A

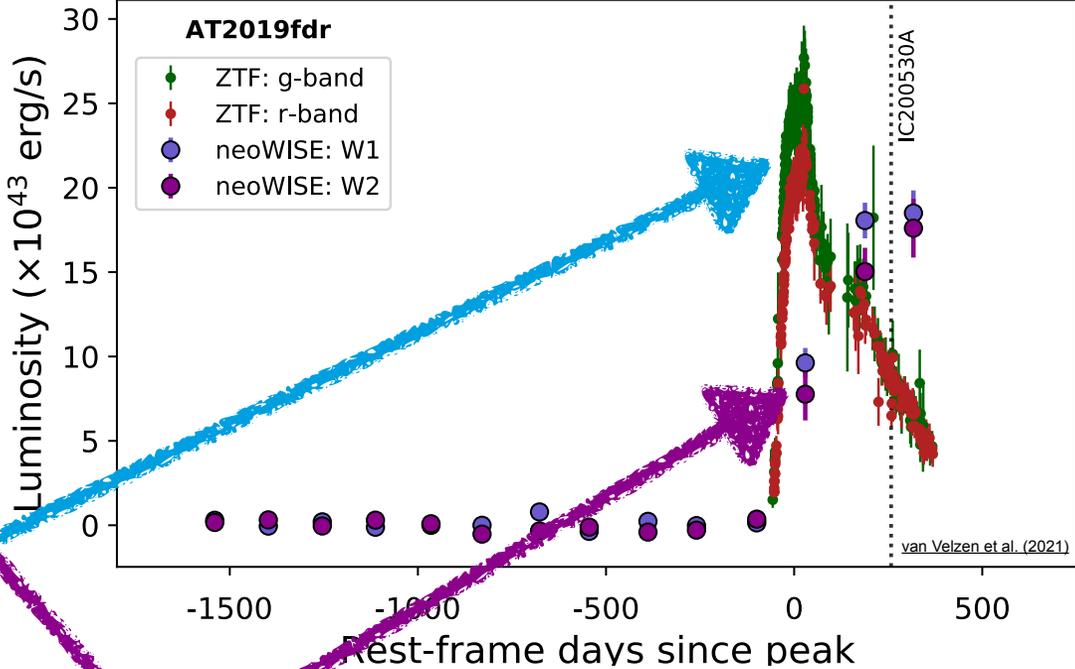
Stein et al. (2021)



optical flare from enhanced accretion onto SMBH

AT 2019fdr + IC200530A

Reusch et al. (2021)



IR flare from **reprocessed emission by dust**, i.e. dust echo

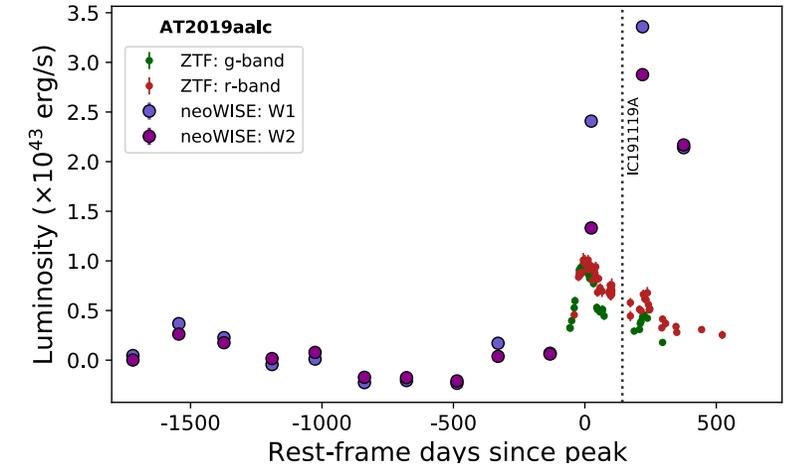
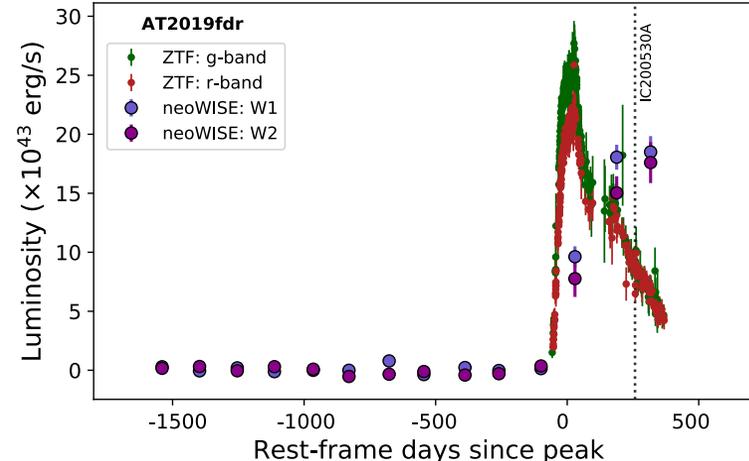
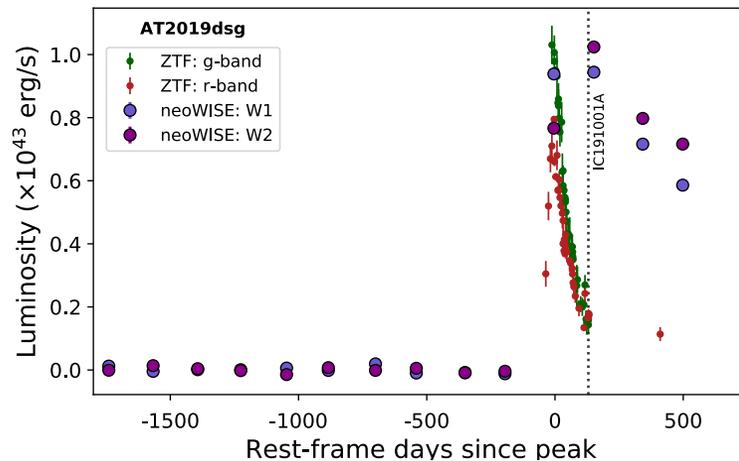
TDE-like Flares

Systematic offline search using similar flares from ZTF:
Three TDEs with dust echos coincident with IceCube alerts

3.7σ correlation of 63 accretion flares with high-energy alerts
→ correlation at lower energies
stacking analysis: test of reported correlation

Establishing accretion flares from massive black holes
as a major source of high-energy neutrinos

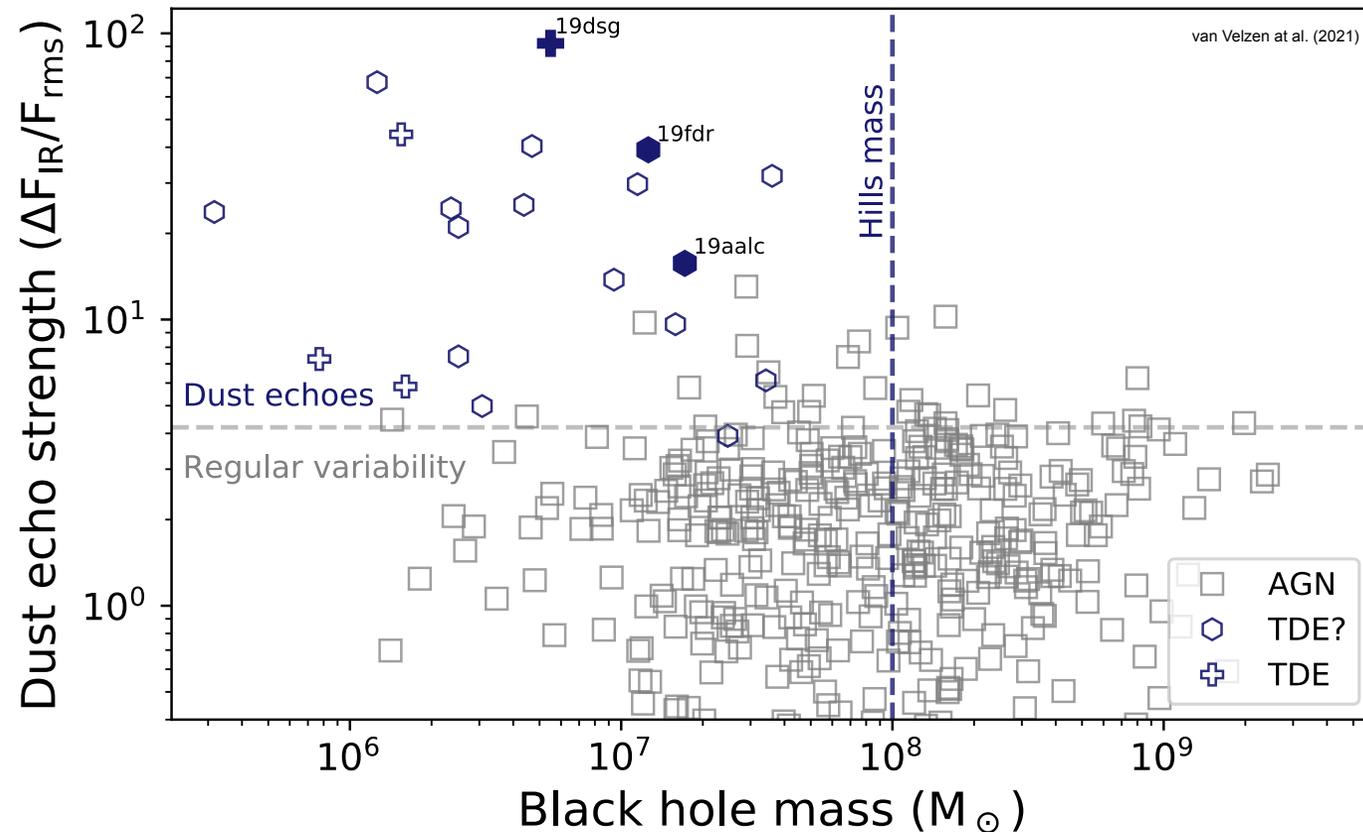
S. van Velzen¹, R. Stein^{2,3}, M. Gilfanov^{4,5}, M. Kowalski^{2,3}, K. Hayasaki^{6,7},
S. Reusch^{2,3}, Y. Yao⁸, S. Garrappa^{2,3}, A. Franczkowiak^{2,9}, C. Fremling¹⁰,
Y. Sharma⁸, L. Yan⁸, E. C. Kool¹², J. Sollerman¹², P. Medvedev⁴,
R. Sunyaev^{4,5}, E. Bellm¹³, R. G. Dekany¹¹, D. A. Duev¹⁰, M. J. Graham¹⁰, M.
M. Kasliwal¹⁰, R. R. Laher¹³, B. Rusholme¹³, and R. L. Riddle¹¹



Stacking Analysis

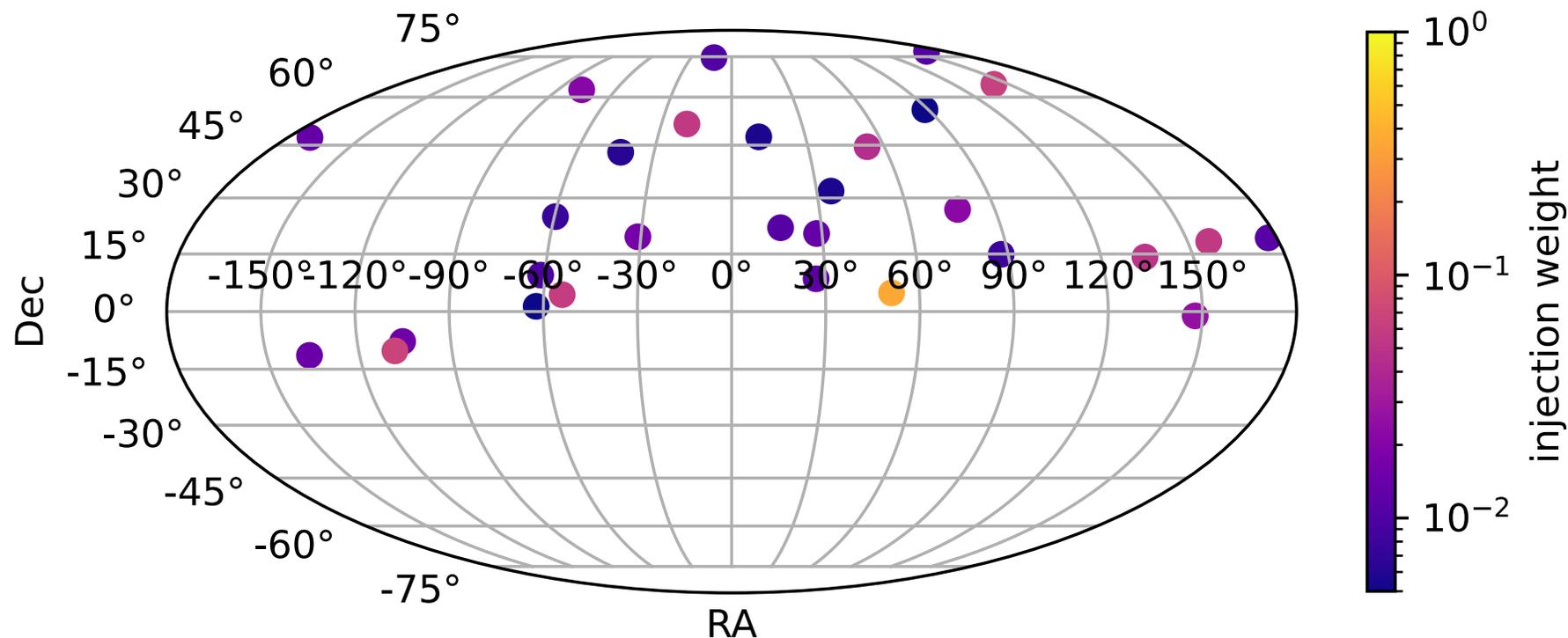
Catalogue

- Flares with alert coincidences among the **brightest dust echos**
- Select **sources above dust echo strength** ($\Delta F_{\text{IR}}/F_{\text{rms}}$) **cut**
- cut at $\Delta F_{\text{IR}}/F_{\text{rms}} > 10$:
almost exclusively **flares that are unlikely due to regular AGN variability**
($P(\text{TDE}) > P(\text{AGN})$)



Stacking Analysis

Catalogue

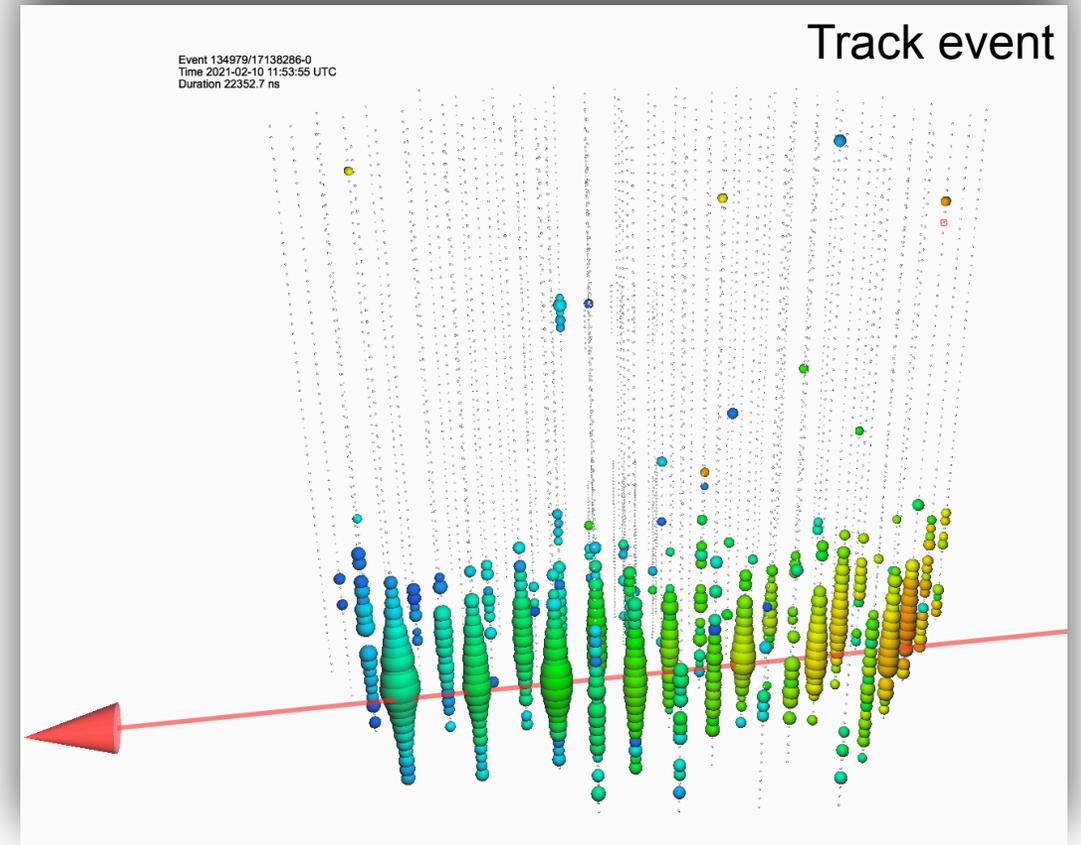


- **29 nuclear flares with large dust echo**
- 2 TDEs, 14 TDE candidates, 15 unknown
- Includes AT2019dsg, AT2019fdr and AT2019aalc
(flares reported coincident with high-energy neutrino alerts)

Stacking Analysis

Dataset

- dataset in **van Velzen et al. (2021)**:
 - 36 high-energy neutrino alerts (processed online)
 - **~80 TeV to ~3 PeV**
- **our dataset**:
 - $\sim 10^6$ track-like events (offline selected)
 - $\sim 10^2$ GeV to ~ 10 PeV
- **same source catalogue with much larger neutrino dataset including lower energies**
⇒ **test of correlation at lower energies**

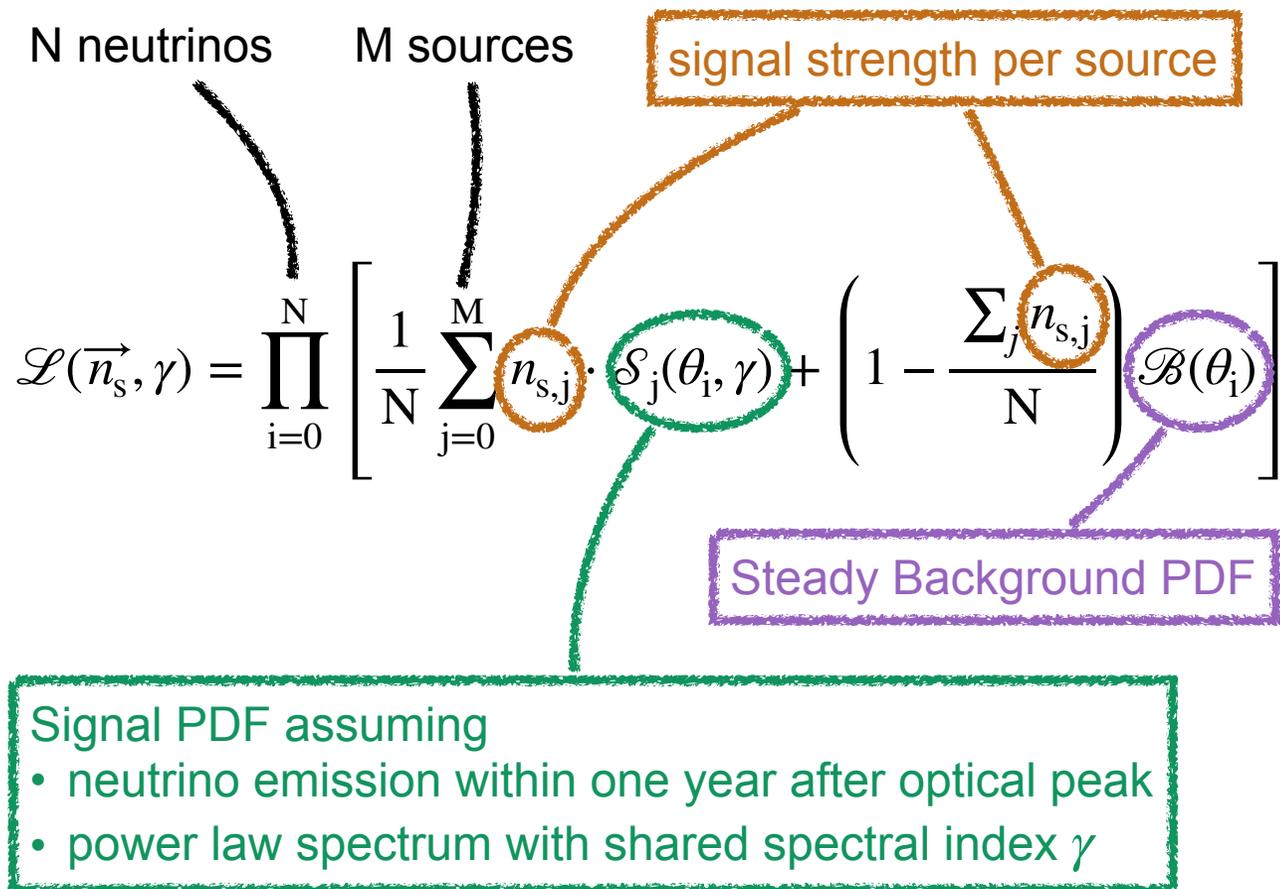


Stacking Analysis

Likelihood Analysis

- **Unbinned maximum likelihood analysis**
- **Stacking** M sources, looking for correlation with N neutrinos
- **30 free parameters**: spectral index γ , **number of neutrinos from each source**:

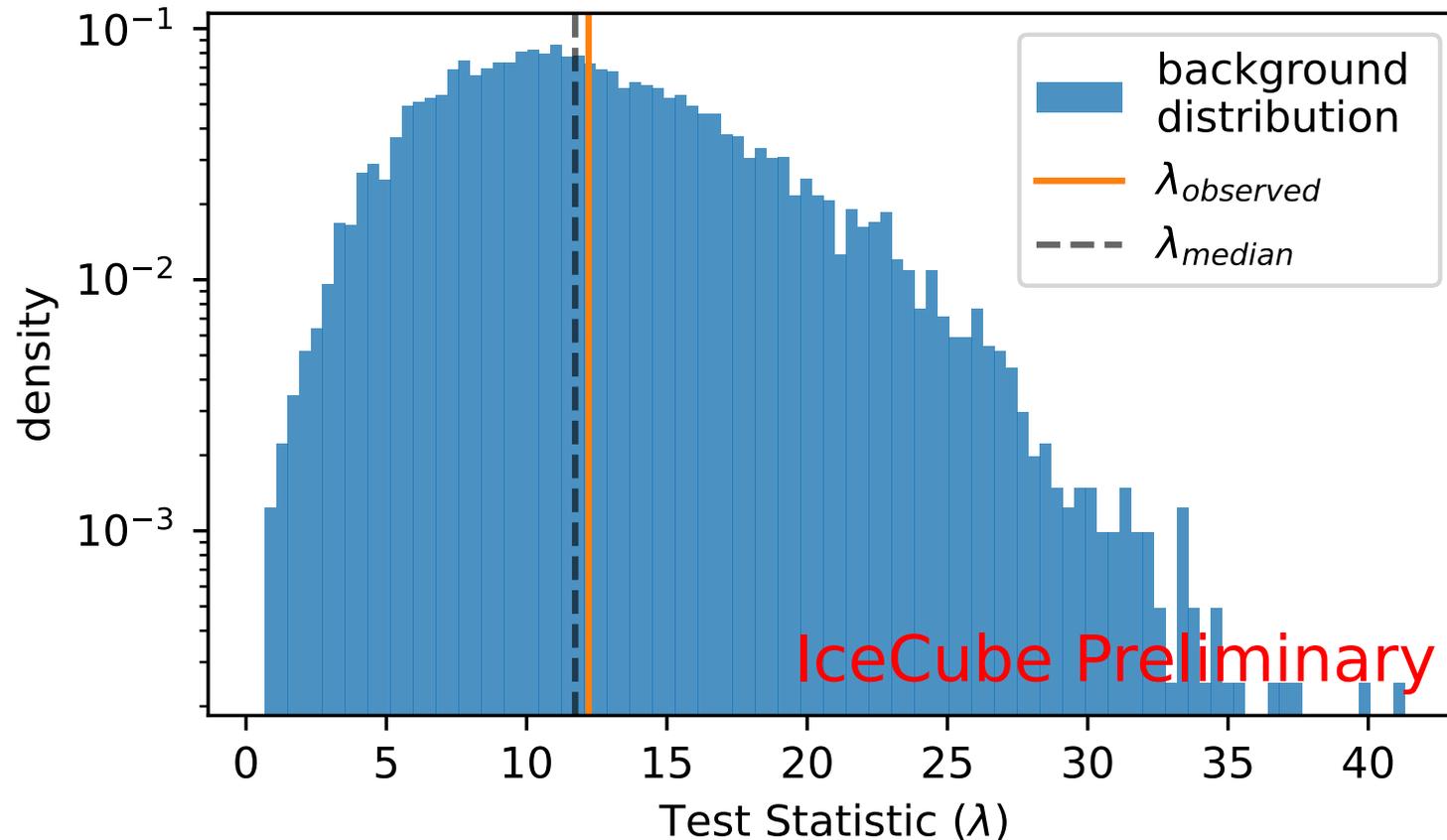
$$\vec{n}_s = (n_{s,1}, n_{s,2}, \dots, n_{s,M})$$



Stacking Analysis

Result

- observed test statistic slightly above background median
- p-value = 0.45

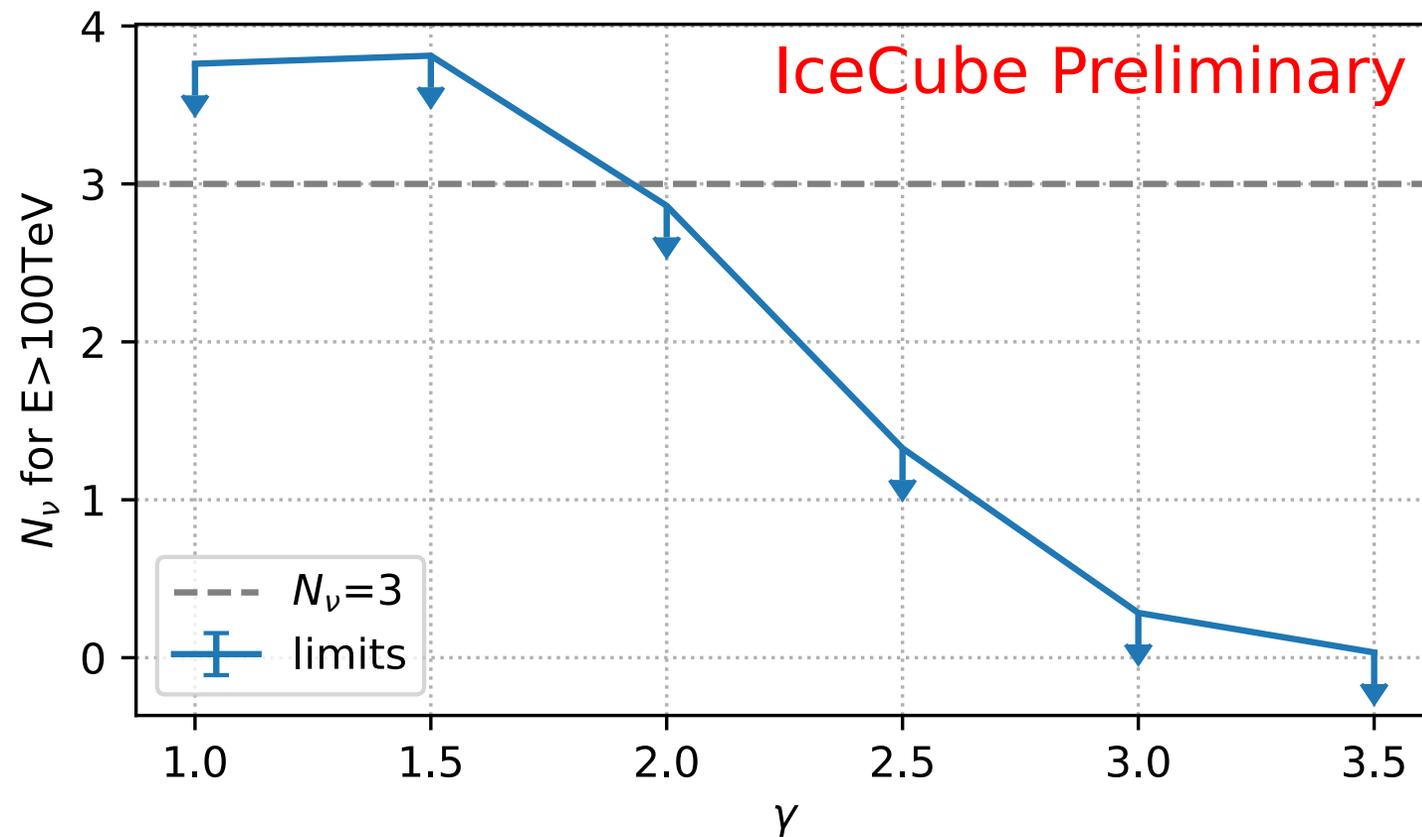


No significant excess in our neutrino dataset from sources in catalogue

Stacking Analysis

Upper limit on alert events

- Number of neutrinos in our dataset N_ν with $E > 100$ TeV:
mimic high-energy neutrino alerts
- Results **consistent with reported three alert events for $\gamma < 2$**



Summary

Sample of TDE-like flares with large dust echoes reported correlated with high-energy alerts

Performed stacking analysis with selection of 29 promising sources and neutrino dataset at lower energies

No significant excess measured

Results consistent with alert associations for hard spectral indices

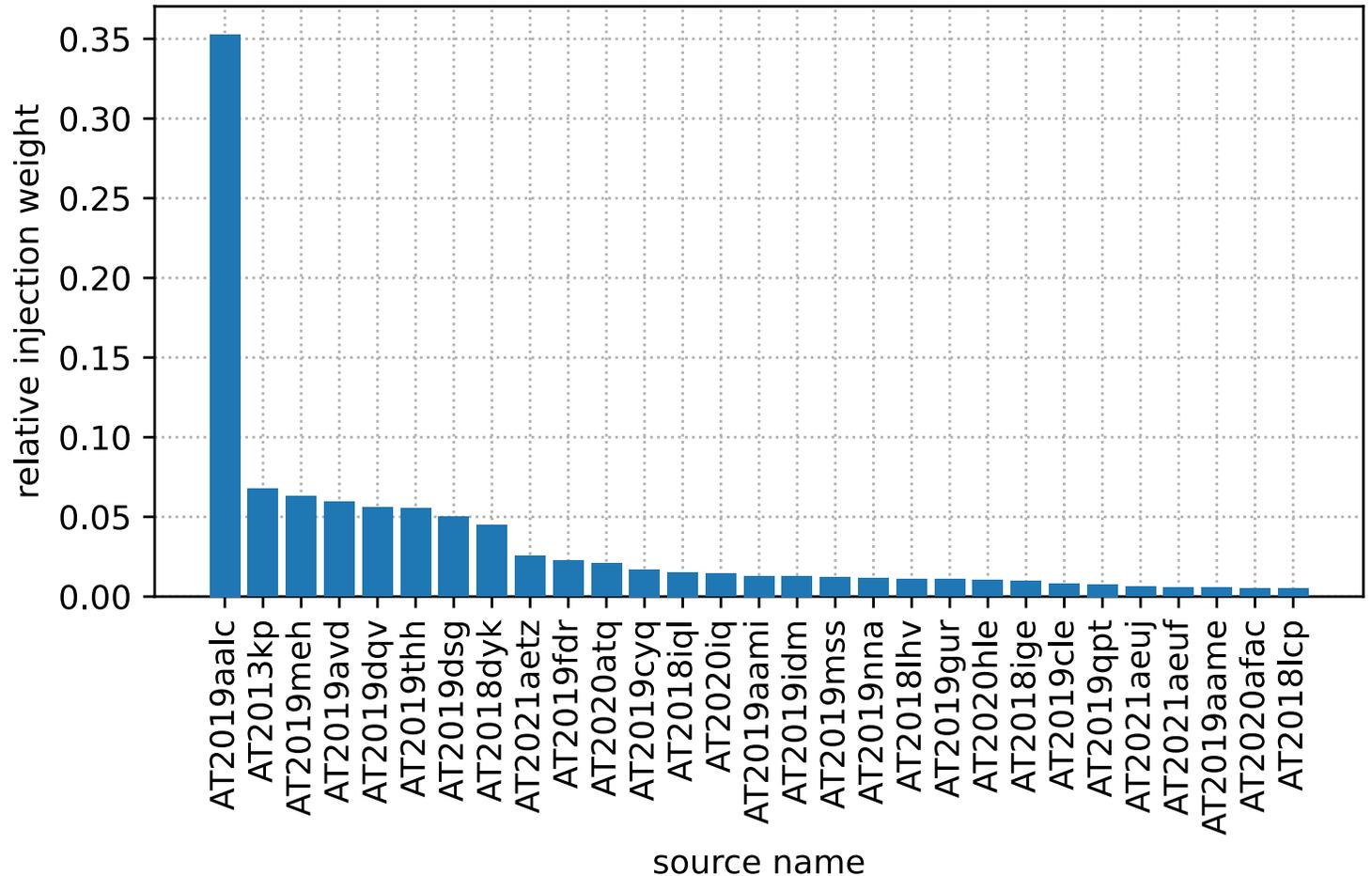


Backup

Catalogue

Injection Weights

- Some sources **without observed redshift**
 - ▶ **No handle on distance**
- Instead: **injection based on total IR dust echo flux**
 - ▶ includes distance
 - ▶ includes **assumption that neutrino flux is proportional to IR dust echo flux**



Stacking Analysis Likelihood

Probability Distribution Functions

▶ **spatial, temporal and energetic behavior uncorrelated for both signal and background**

▶ signal PDF for source j : $\mathcal{S}_j(\nu_i) = \mathcal{N}_{\mathcal{S},j}(r_i, \sigma_i) \times \mathcal{T}_{\mathcal{S},j}(t_i) \times \mathcal{E}_{\mathcal{S},j}(E_i, \delta_i \gamma)$

▶ background PDF: $\mathcal{B}(\nu_i) = \mathcal{N}_{\mathcal{B}}(r_i) \times \mathcal{T}_{\mathcal{B}}(t_i) \times \mathcal{E}_{\mathcal{B}}(E_i, \delta_i)$

▶ **spatial PDFs:**

▶ **signal is a point source**, modeled as 2-D gaussian

▶ **data is background dominated** \Rightarrow spatial background PDF modeled from data

▶ **temporal PDFs:**

▶ **signal contained within one year from the optical peak** of the flare

▶ **background is uniform** in time

▶ **energy PDFs:**

▶ **signal behaviour captured by MC** simulations, dependent on declination and spectral index

▶ **data is background dominated**, declination dependent only

Where are the alert events?

- **Alerts events** reported coincident with AT2019aalc and AT2019dsg **present in our dataset**
- Likelihood scans for $n_{s, \text{AT2019aalc}}$ and $n_{s, \text{AT2019dsg}}$ **consistent with more than one associated neutrino at 1σ level**

