Neutrino Follow-Up with the Zwicky Transient Facility

Results from the first 24 campaigns

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TeVPA 2022, Kingston, Canada

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Neutrino follow-up with the Zwicky Transient Facility: Results from the first 24 campaigns

https://arxiv.org/abs/2203.17135

Robert Stein [1,2,3]★, Simeon Reusch [1,2], Anna Franckowiak [1,2,4], Marek Kowalski [1,2], Jannis Necker [1,2], Sven Weimann [4], Mansi M. Kasliwal [3], Jesper Sollerman [5], Tomas Ahumada [6,7]†, Pau Amaro Seoane [8,9,10], Shreya Anand [3], Igor Andreoni [11,12,13], Eric C. Bellm [14], Joshua S. Bloom [15,16], Michael Coughlin [17], Kishalay De [18], Christoffer Fremling [3], Suvi Gezari [19], Matthew Graham [3], Steven L. Groom [20], George Helou [20], David L. Kaplan [21], Viraj Karambelkar [3], Albert K.H. Kong [22], Erik C. Kool [5], Massimiliano Lincetto [4], Ashish A. Mahabal [3,23], Frank J. Masci [20], Michael S. Medford [15,16], Robert Morgan [24], Jakob Nordin [2], Hector Rodriguez [25], Yashvi Sharma [3], Jakob van Santen [1], Sjoert van Velzen [26], Lin Yan [25]

Simeon Reusch

DESY

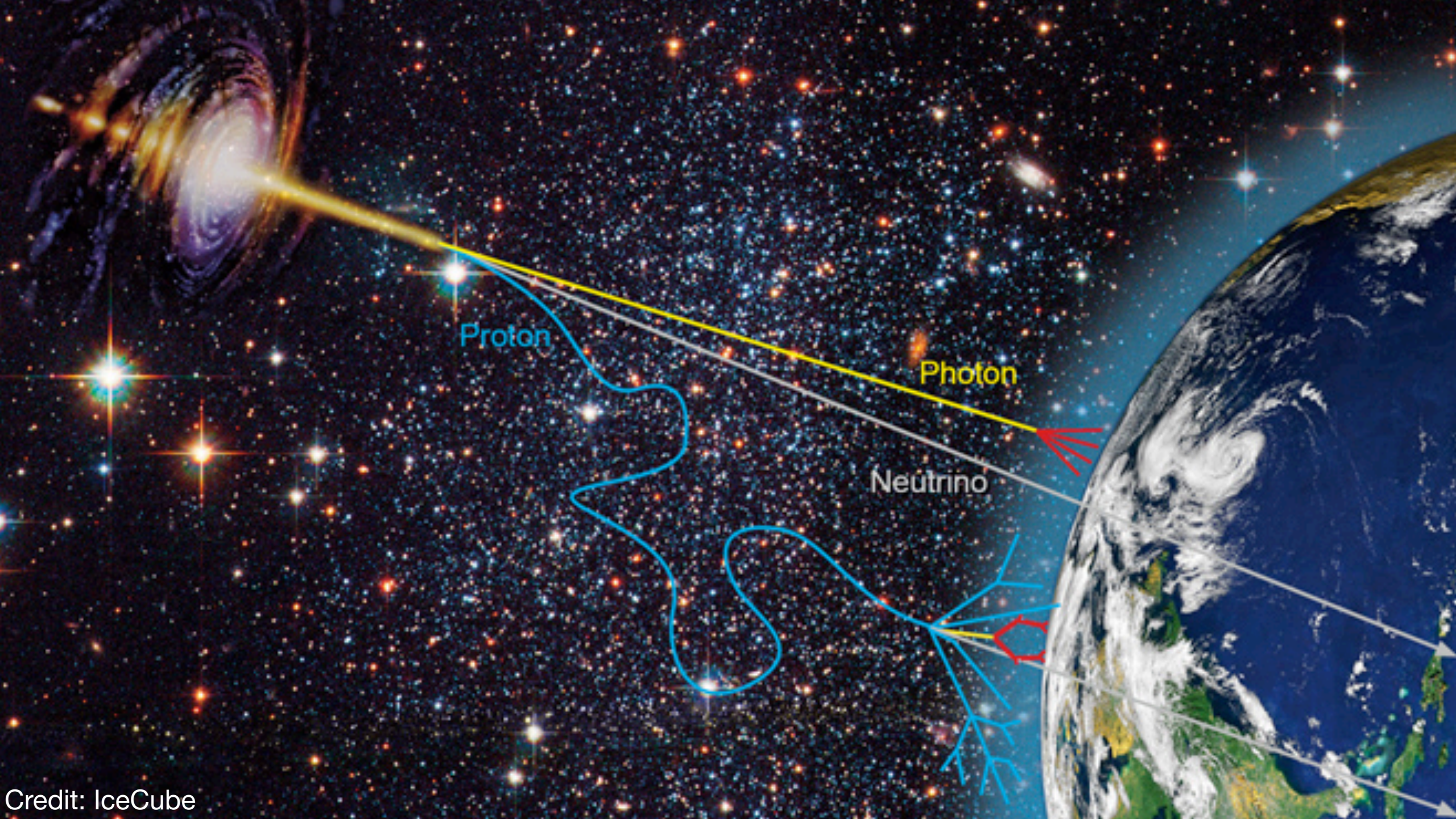
Jannis Necker

DESY

Sven Weimann

RUB

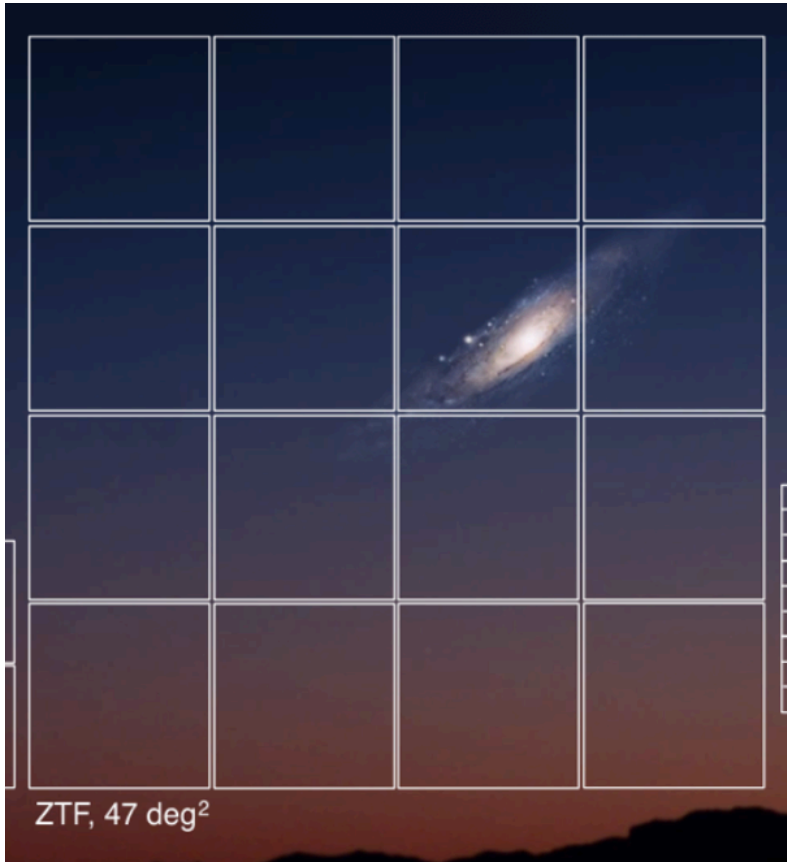
Astrophysical Neutrinos



Credit: IceCube

Neutrino Follow-up with ZTF

Introducing the Zwicky Transient Facility



Credit: Iair Arcavi

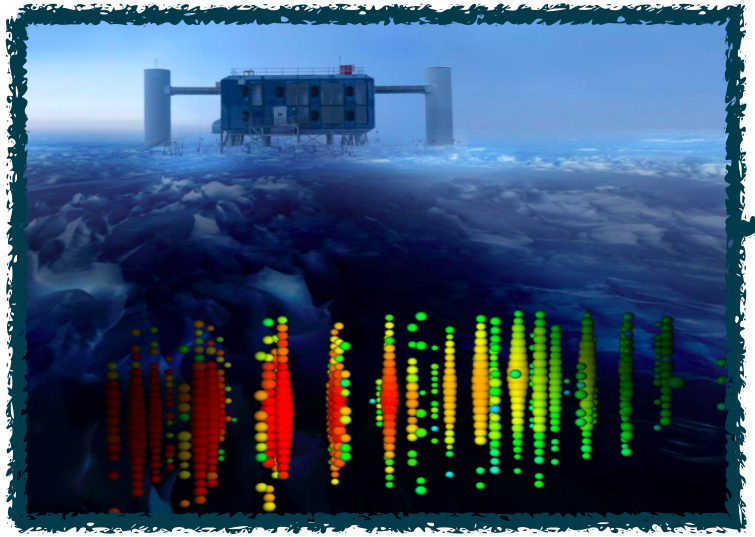
ZTF is an optical telescope with a 47 sq. deg. field of view

Surveys the entire northern sky every 2 nights, in g+r, as part of a public survey

The ZTF neutrino follow-up program

Stein et al. 2022

Credit: Iair Arcavi



Credit: IceCube

~500k objects per night

NuZTF

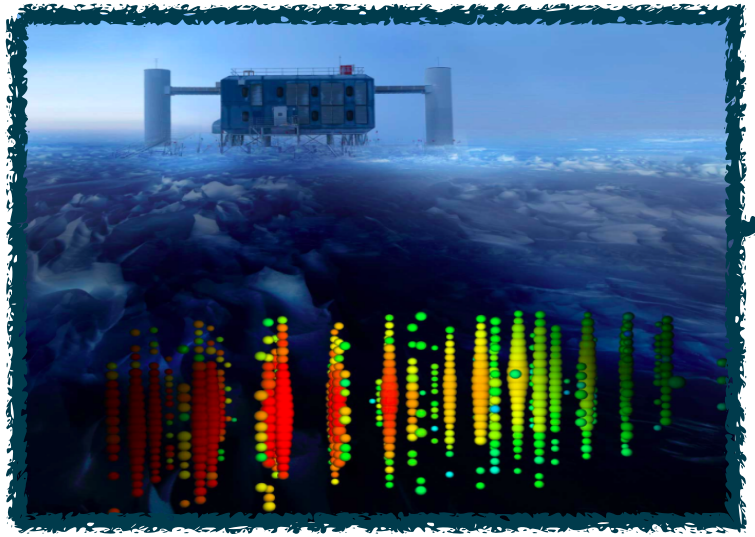
Neutrino direction and time

Find counterpart?

The ZTF neutrino follow-up program

Stein et al. 2022

Credit: Iair Arcavi



Credit: IceCube

~500k objects per night

Neutrino direction and time

NuZTF

Reject stars, asteroids, planets

Correlate

Spectroscopically classify few remaining objects

Find counterpart?

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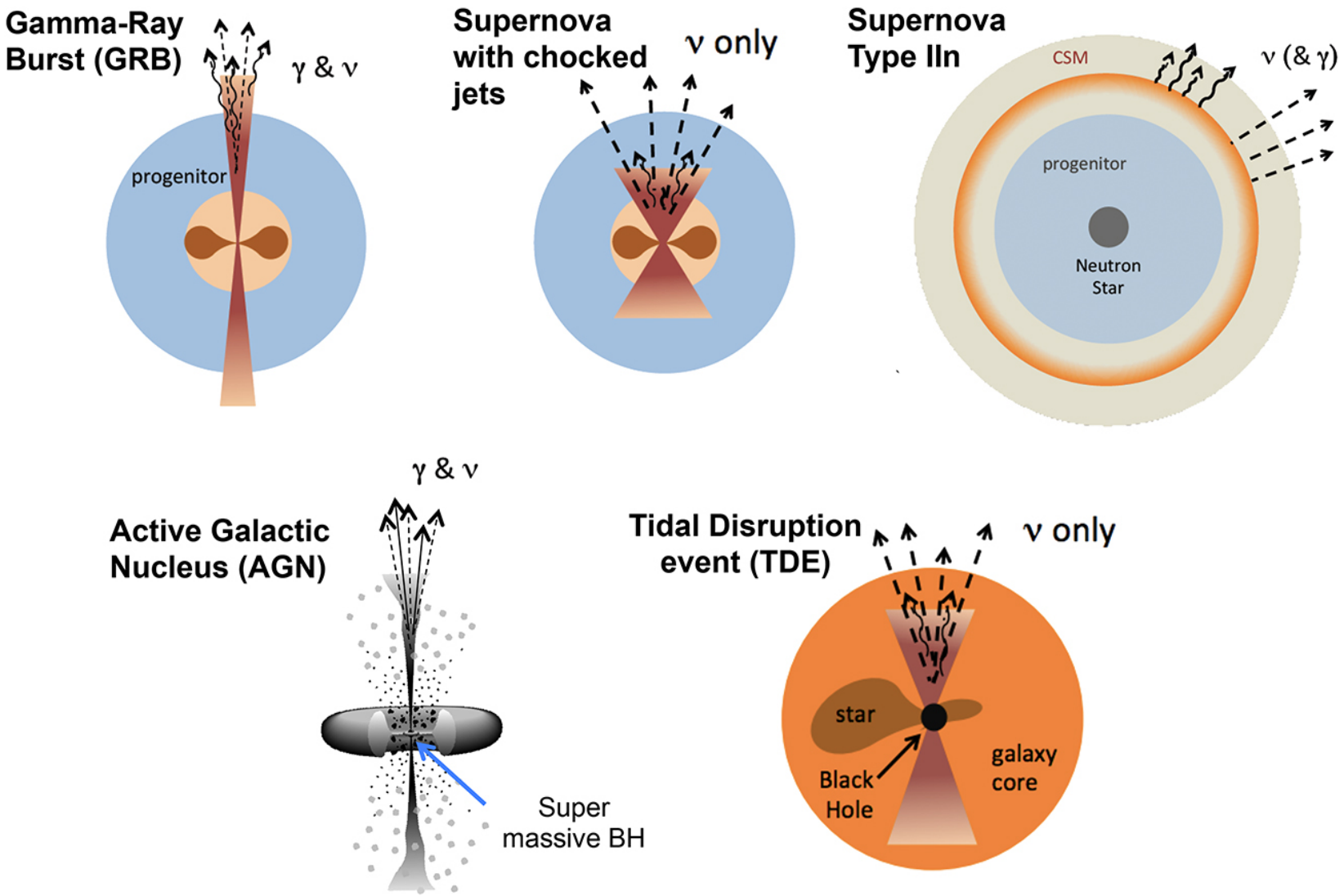
What are we looking for?

Bartos and Kowalski 2017



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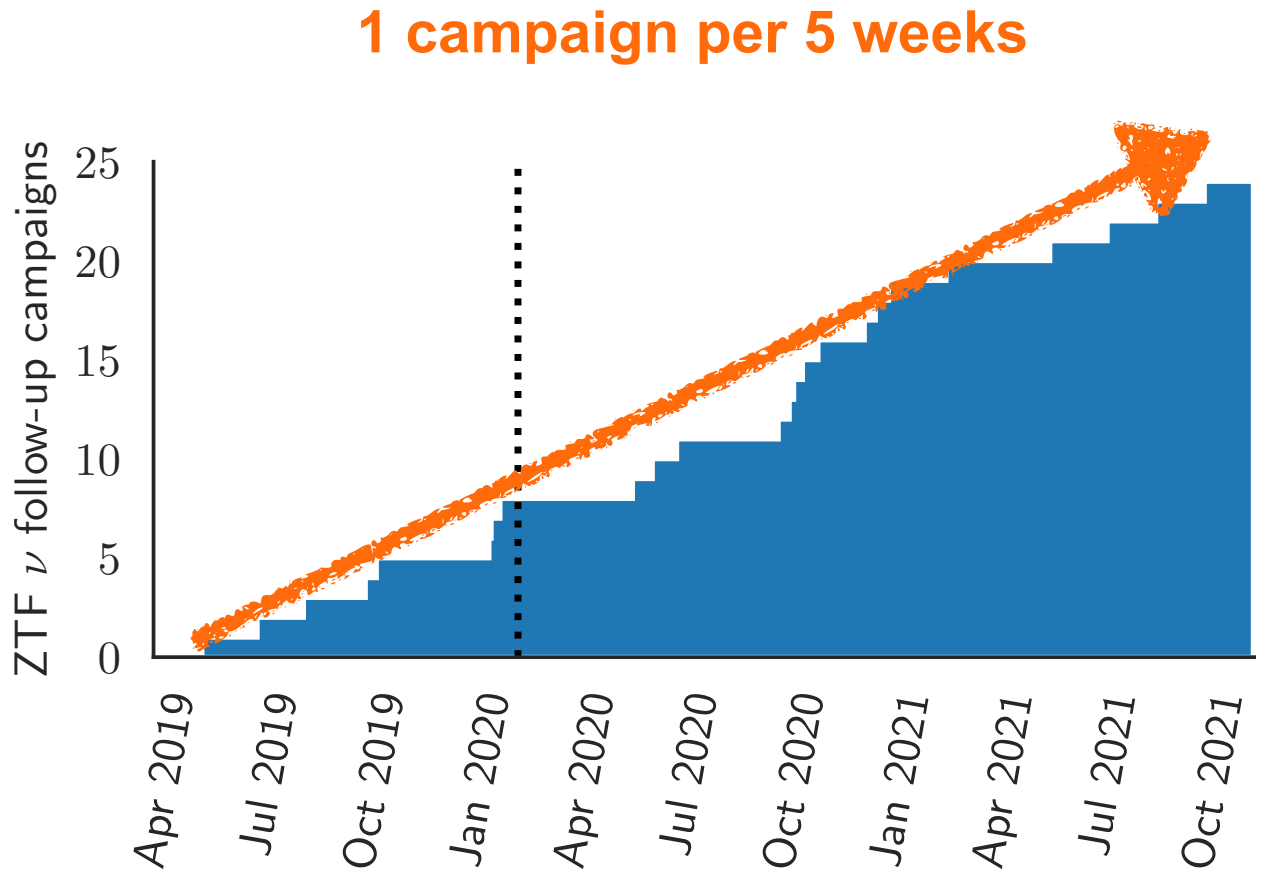
How well are we doing?

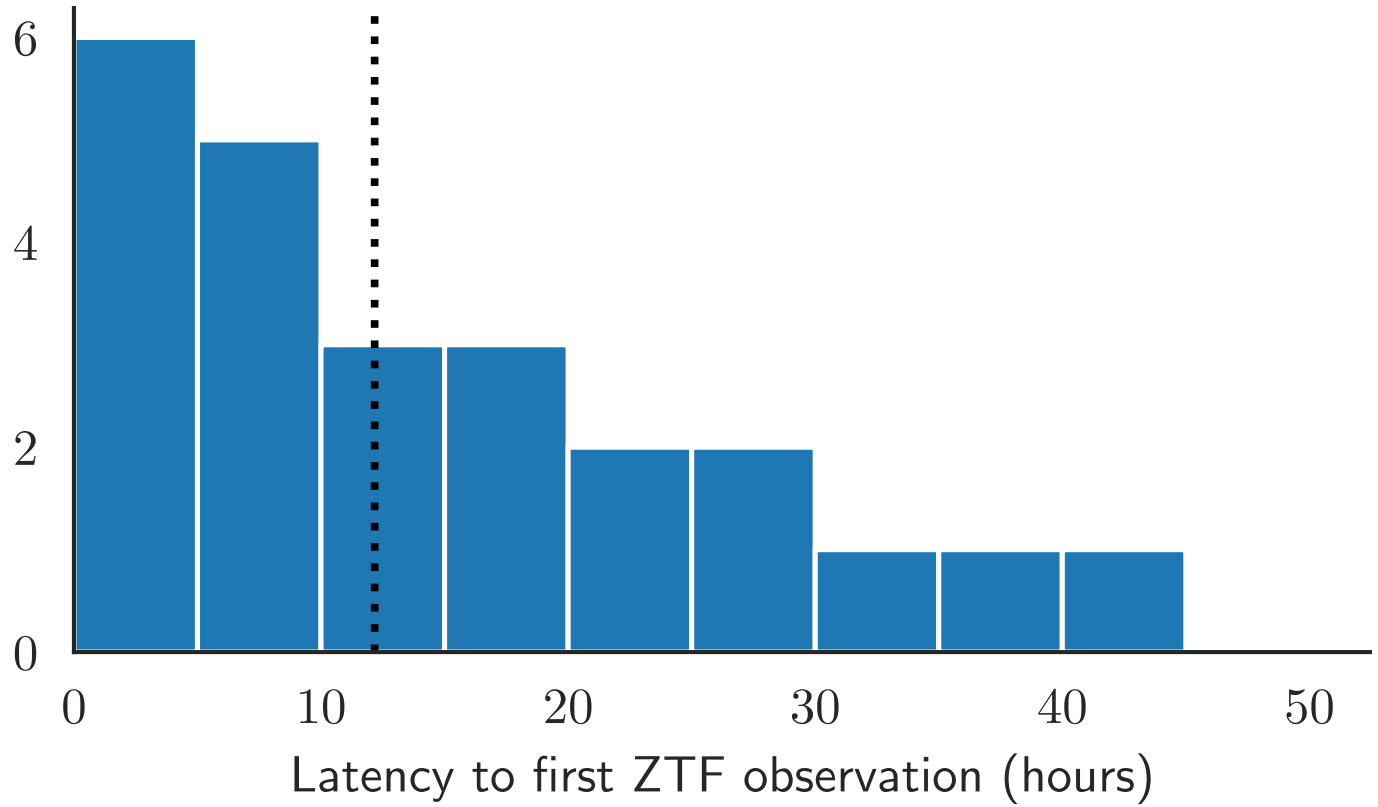
Some statistics…



Stein et al. 2022

Some statistics…

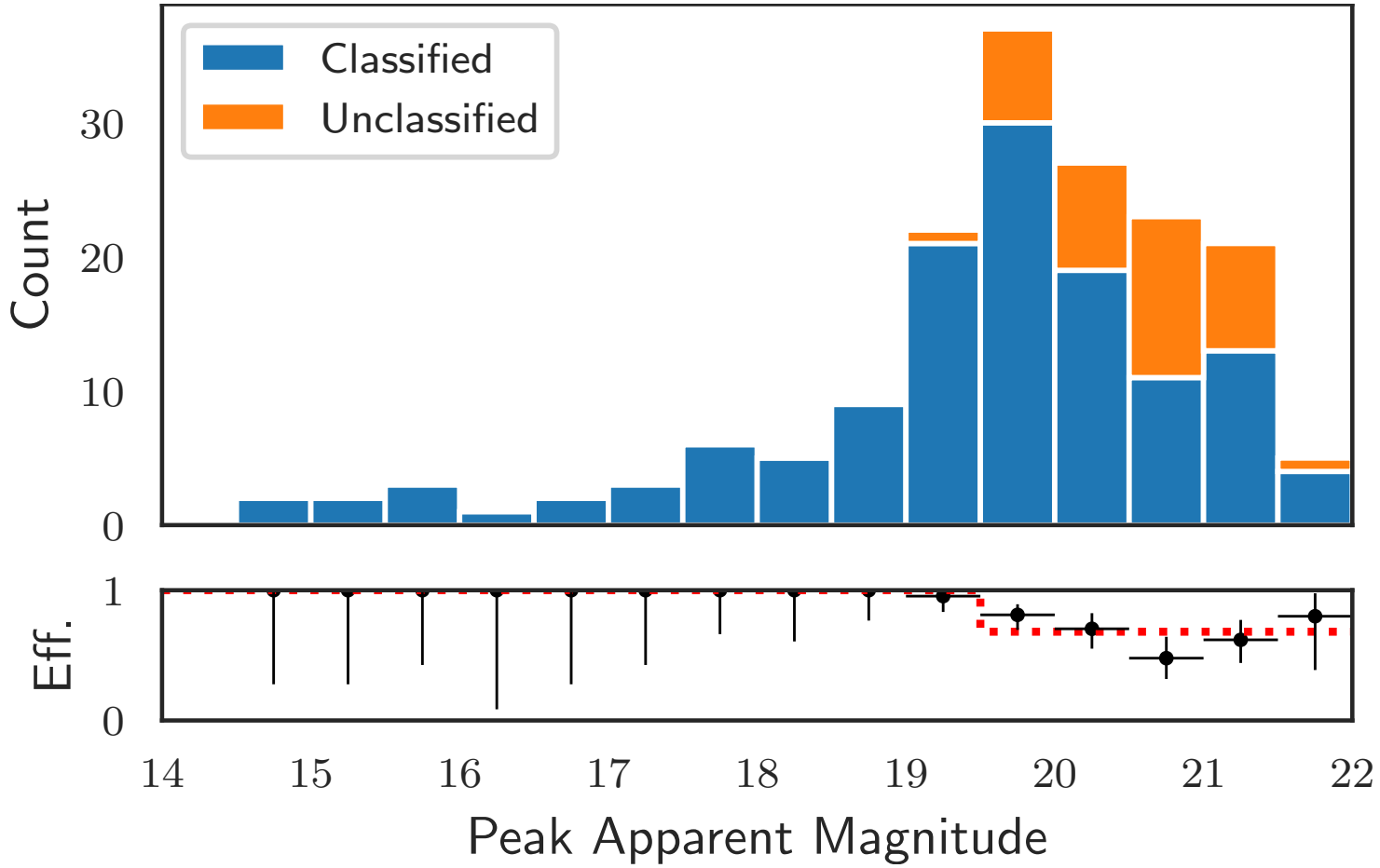
Median latency of 12 hours from neutrino detection to ZTF observation



Stein et al. 2022

Some statistics…

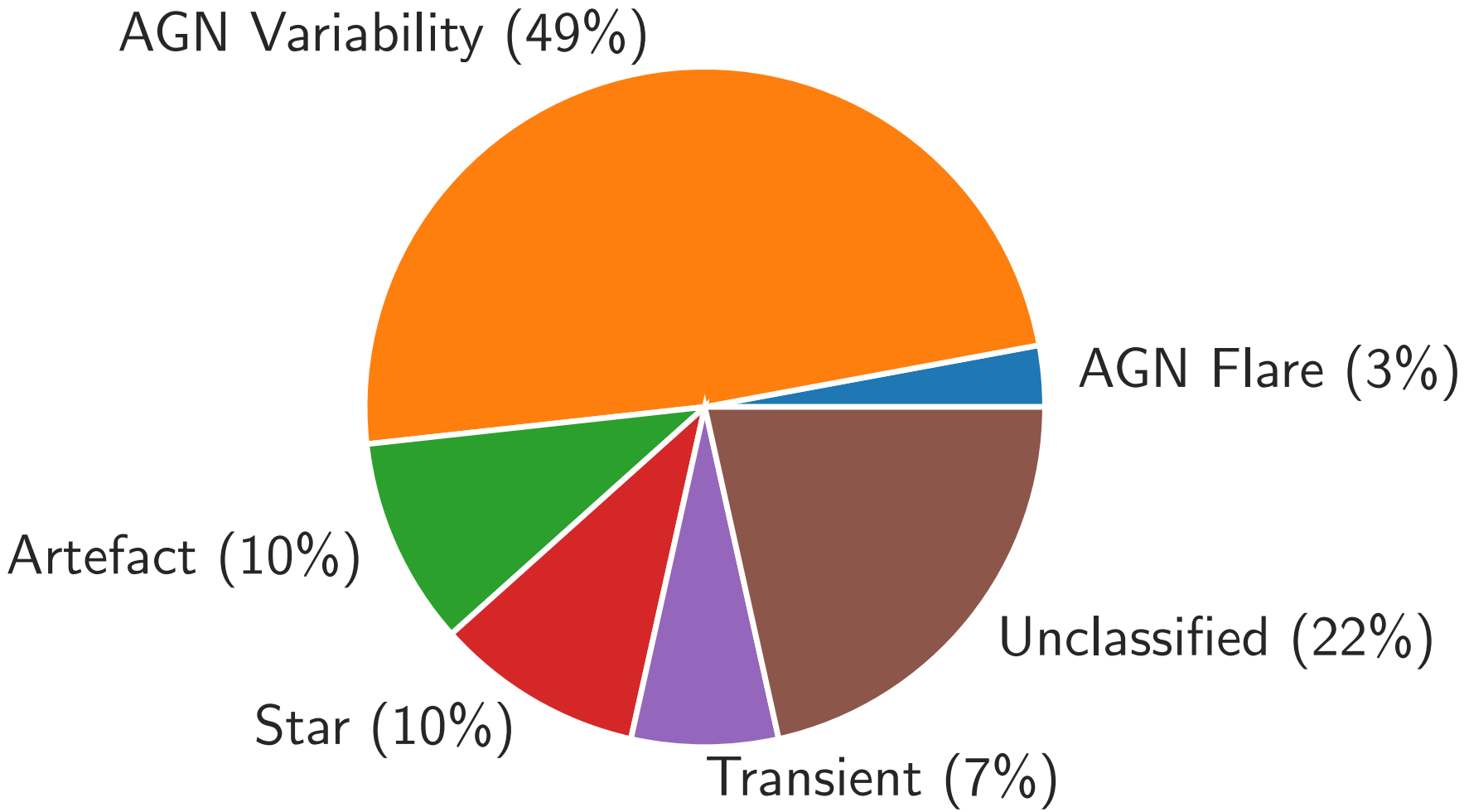
We classify ~100% of bright sources and ~70% of fainter ones



Stein et al. 2022

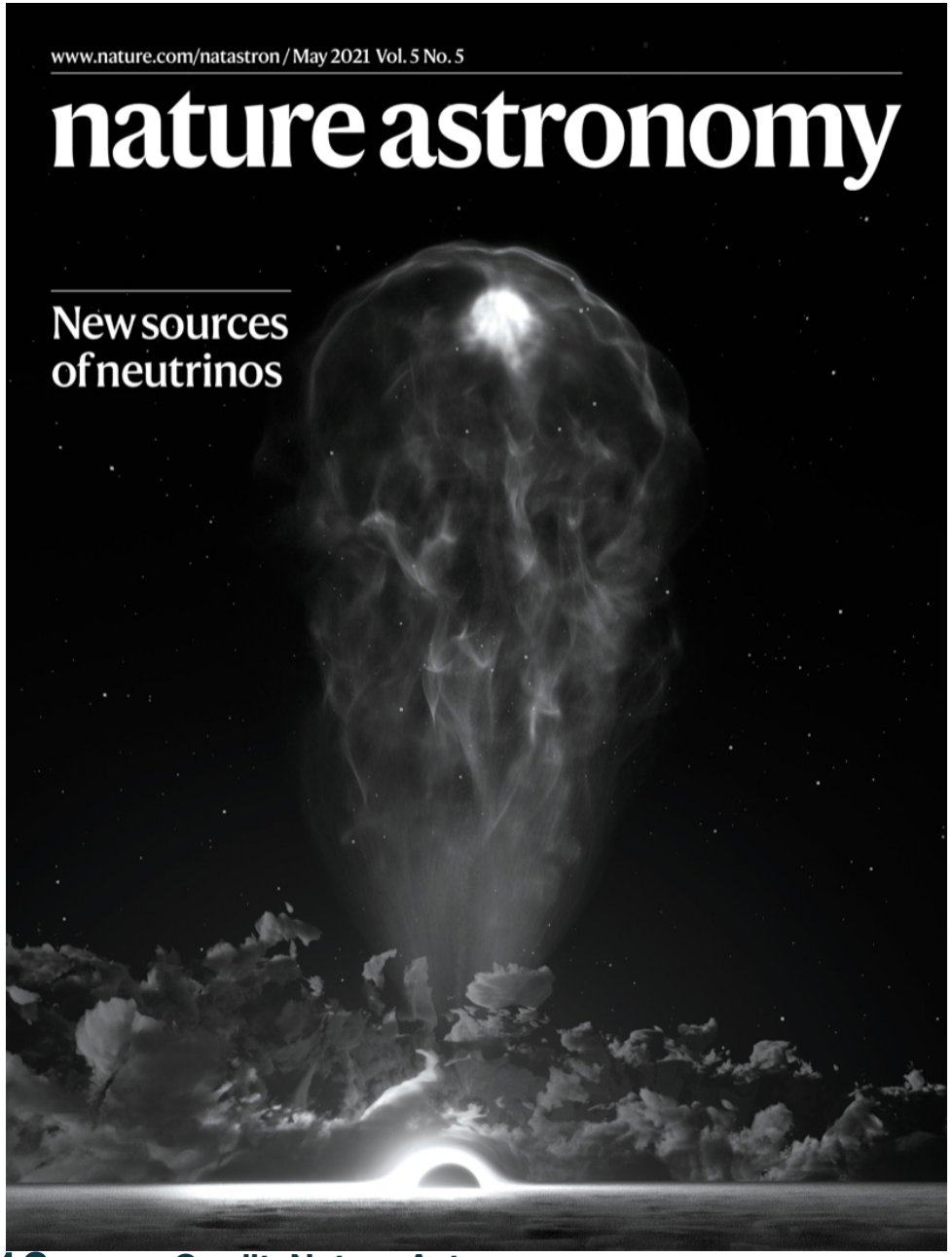
Some statistics…

Only a small fraction of 172 candidates are ultimately transients



What did we find?

Two TDEs coincident with neutrinos



Credit: Nature Astronomy

ARTICLES
https://doi.org/10.1038/s41550-020-01295-8
nature astronomy
Check for updates

A tidal disruption event coincident with a high-energy neutrino

Stein et al. 2021

Featured in Physics | Editors' Suggestion

Candidate Tidal Disruption Event AT2019fdr Coincident with a High-Energy Neutrino

Simeon Reusch *et al.*
Phys. Rev. Lett. **128**, 221101 – Published 3 June 2022

Physics See Focus story: Neutrinos from a Black Hole Snack

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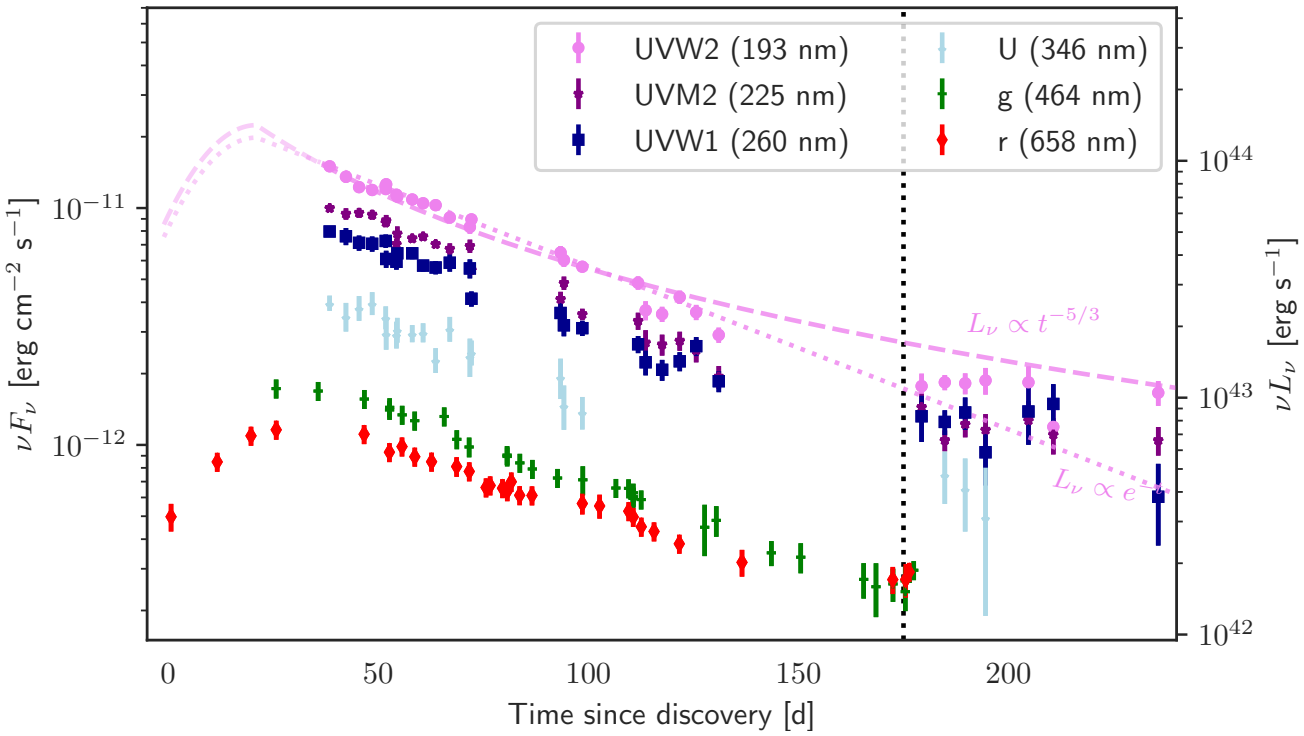
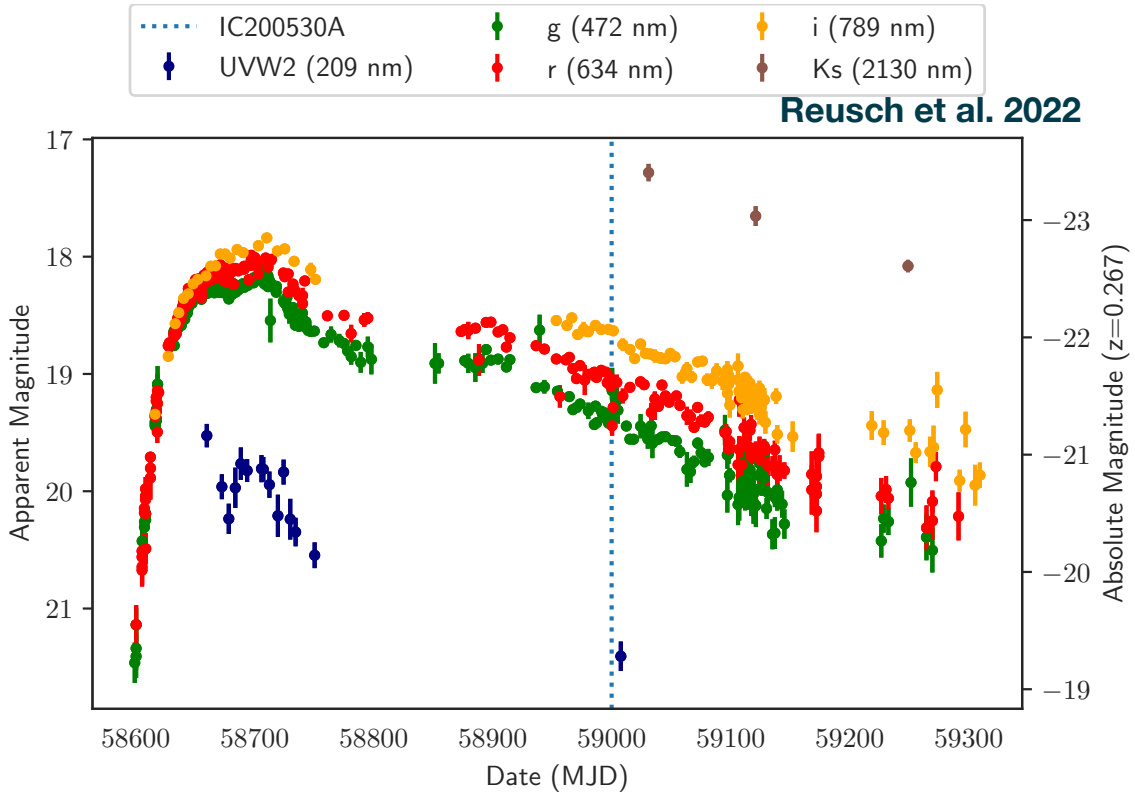
From 24 neutrino follow-up campaigns -> Now two neutrino-TDEs

Stein et al. 2021



AT2019dsg

Reusch et al. 2022



AT2019fdr

ZTF program uncovered 2 likely neutrino-TDEs out of 24 follow-up campaigns, both particularly bright

Probability of finding two bright TDE by chance with ZTF program: (0.034%=3.4σ)

See Cecilia's talk from this morning for more info on this

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What did we not find?

How likely are you to actually find a counterpart?

24 neutrino alerts

Account for astrophysical probability (typically ~50%)

Account for fraction of localisation observed (~60-90%)

Assume a population of neutrinos sources with a particular redshift evolution (e.g SFR)

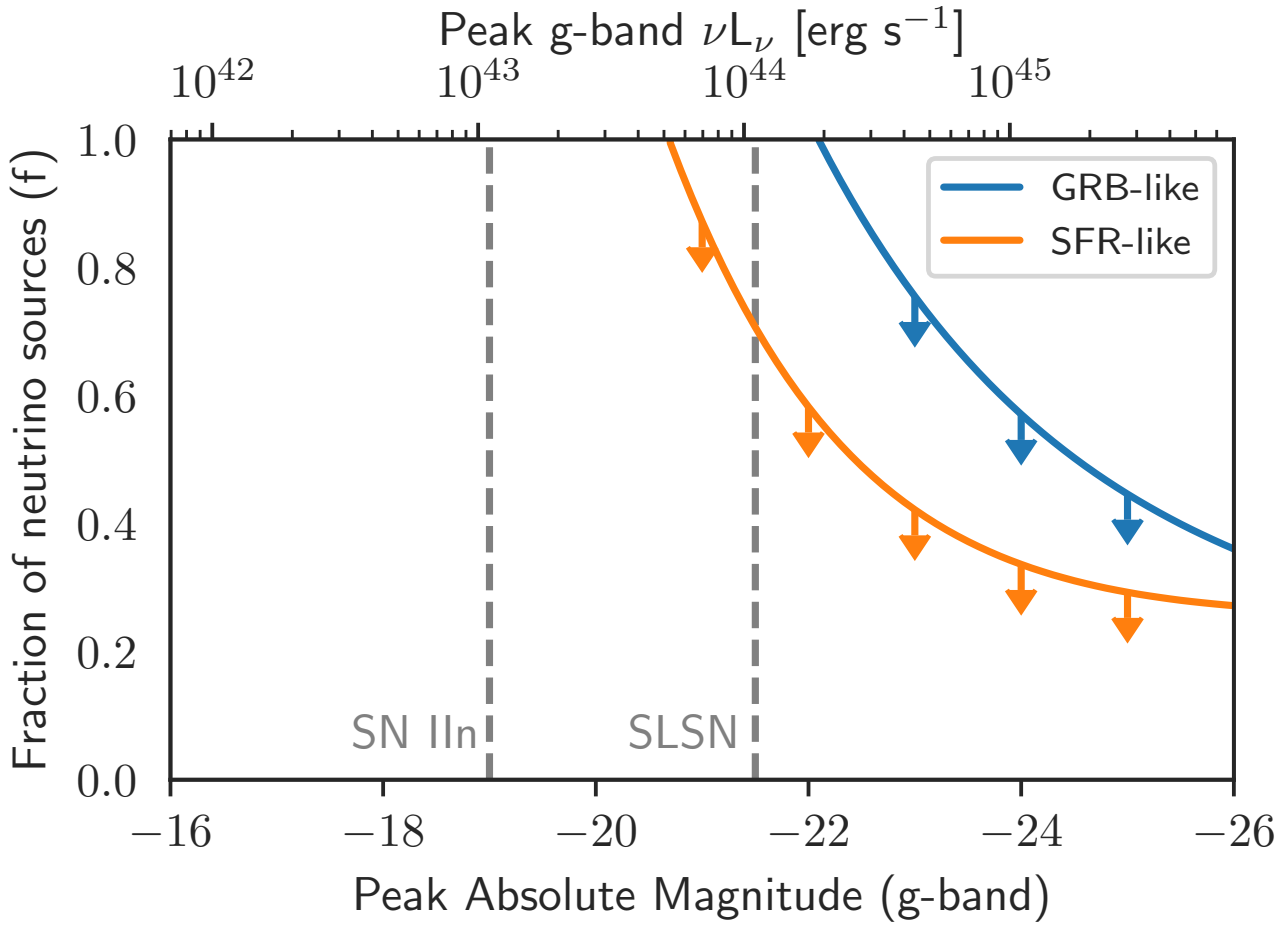
Estimate what fraction of sources would be detectable with ZTF for a given source source luminosity

Use our classification efficiency (~70% for faint sources)

Calculate probability to detect a counterpart in at least one of our campaigns

Limits on non-TDE neutrino source populations

Stein et al. 2022



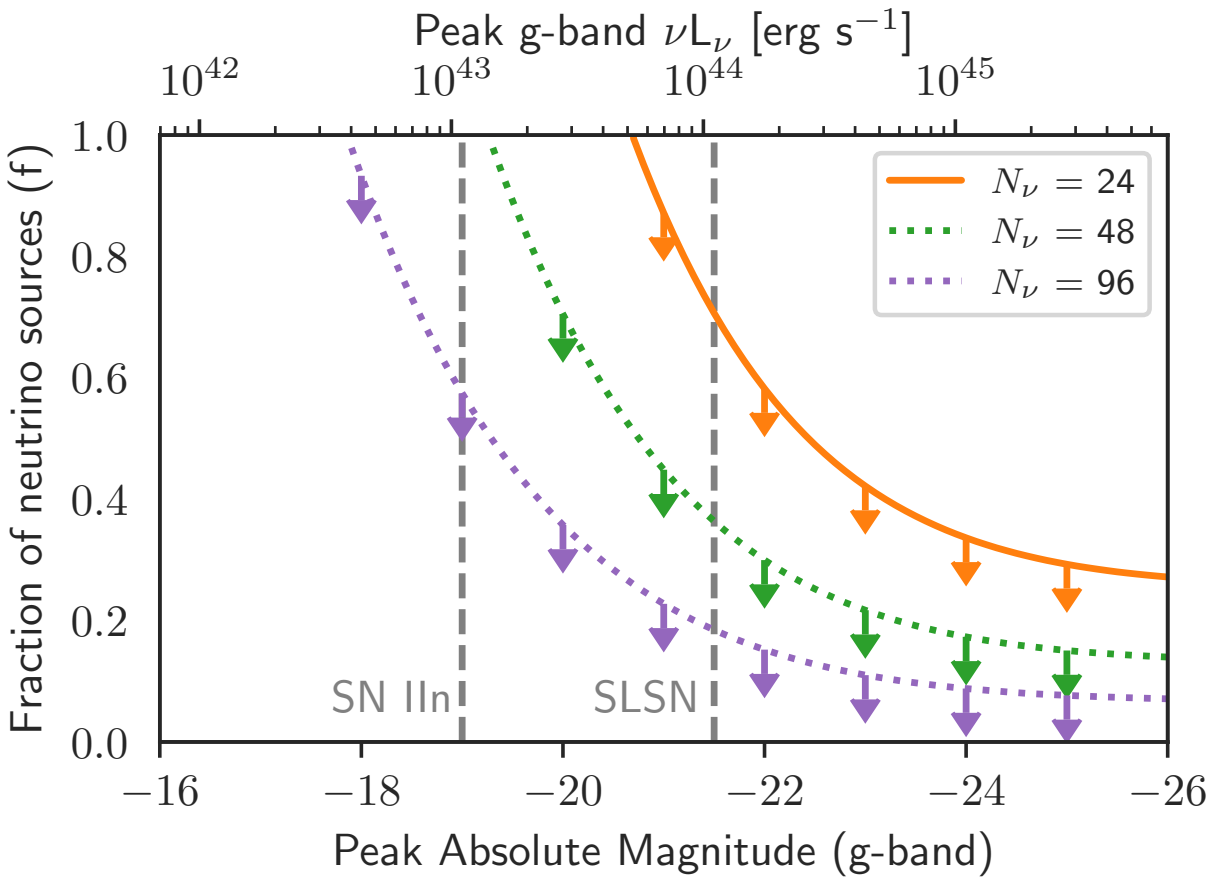
From 24 campaigns -> first constraints on the optical luminosity function of neutrino sources

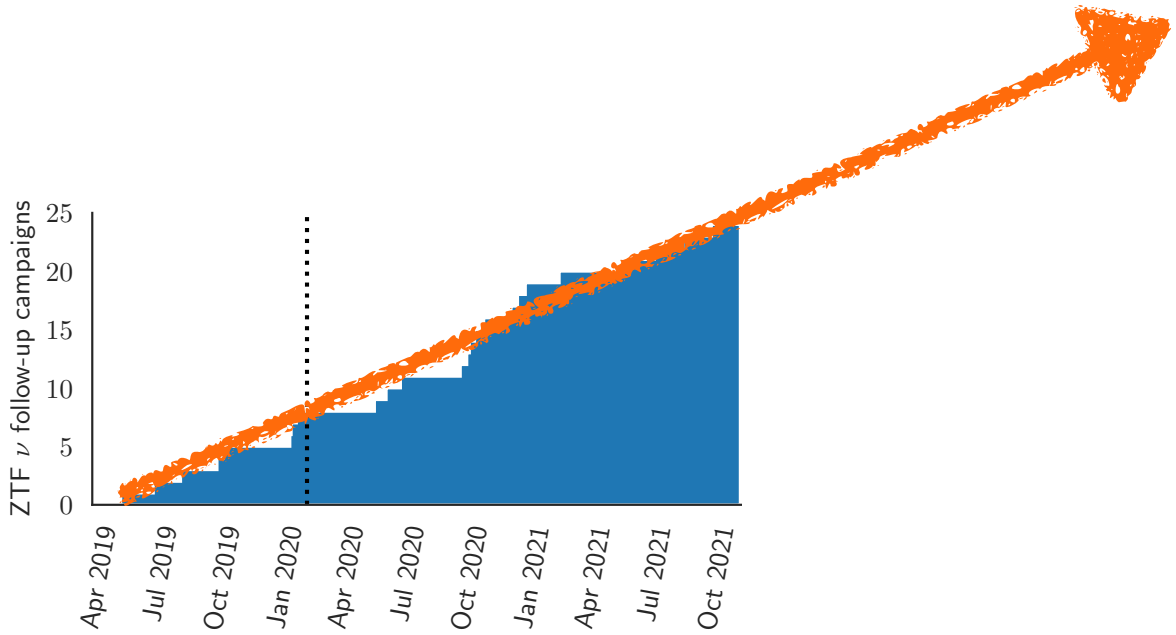
How can we do better in future?

How can we do better?

Stein et al. 2022

More campaigns





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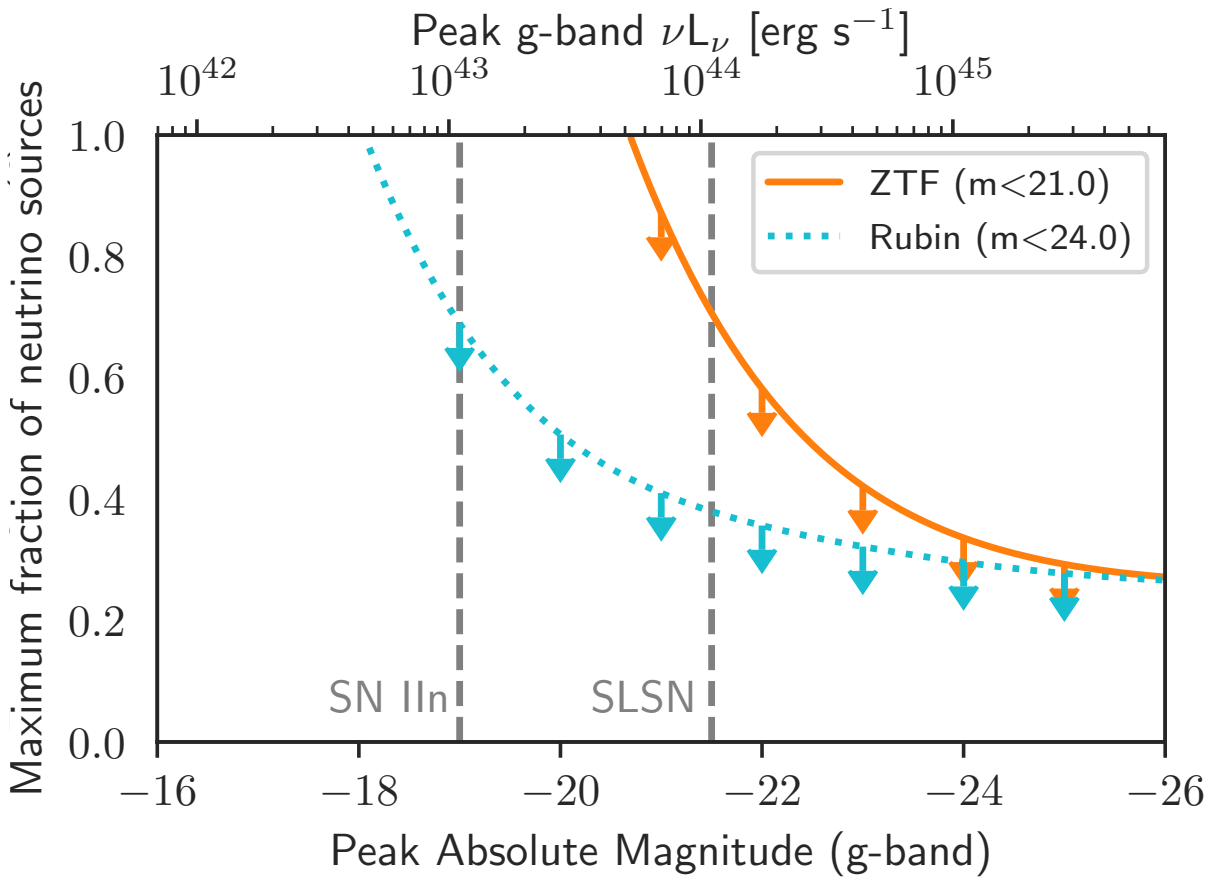
How can we do better?

Stein et al. 2022

Deeper campaigns



Credit: Bruno C. Quint

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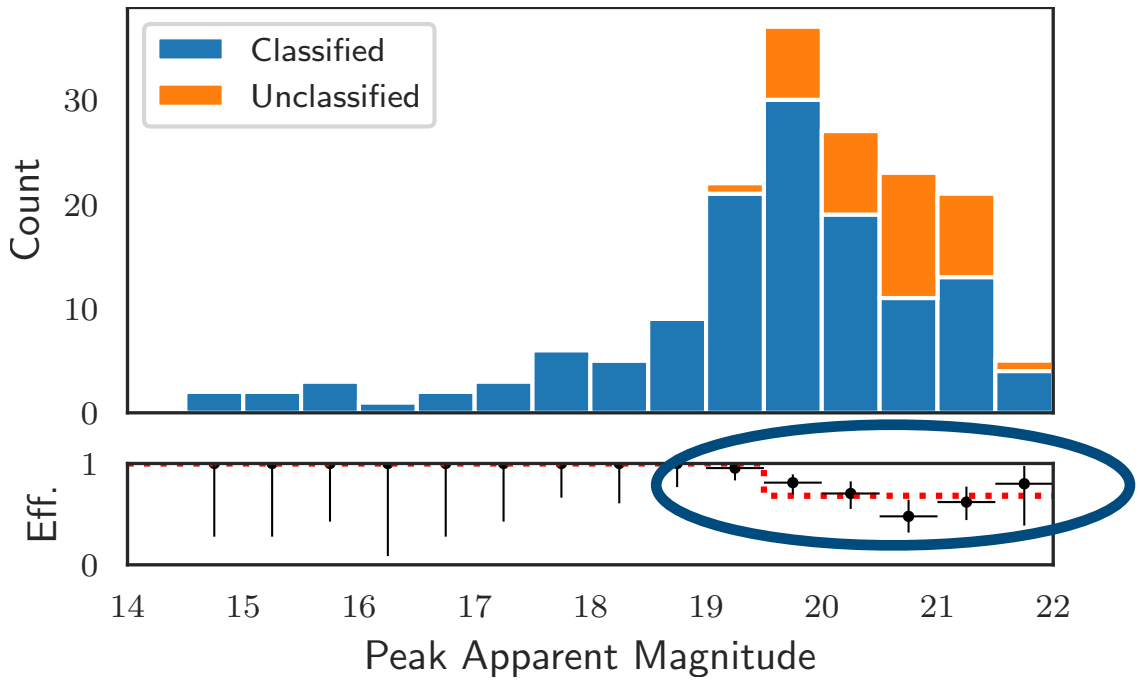
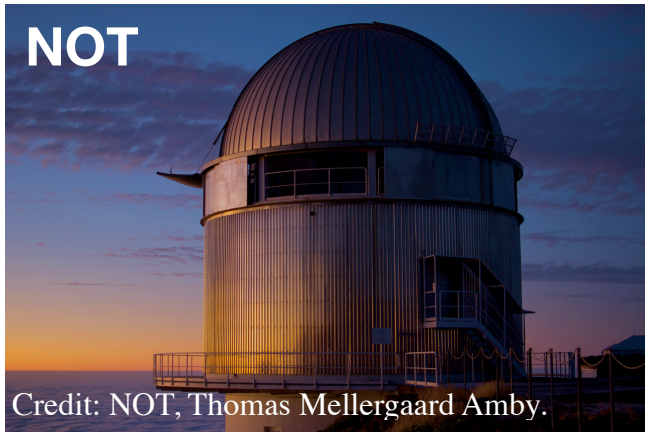
How can we do better?

Stein et al. 2022

Better completeness





How can we do better?

New Wavelengths!

Credit: Robert Stein

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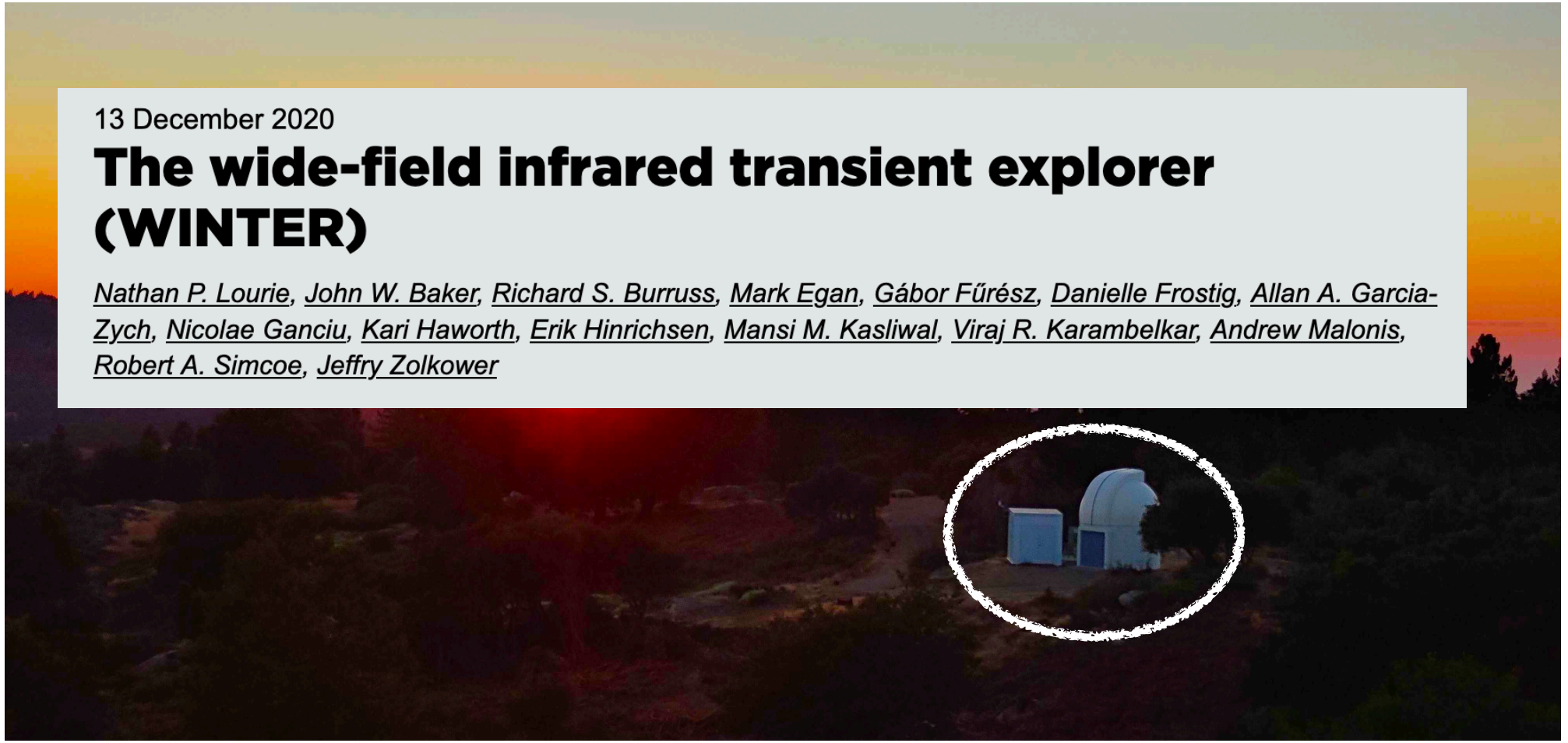
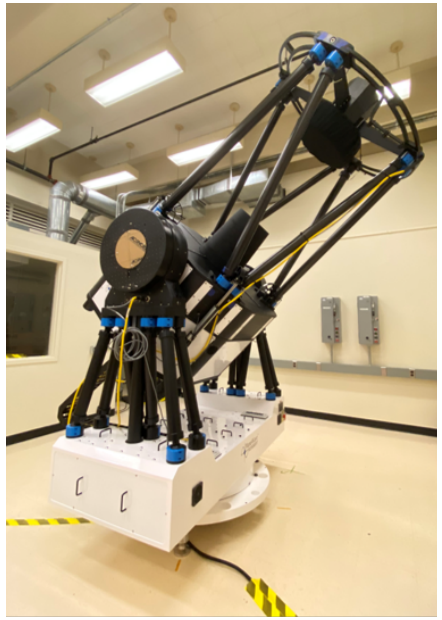
New Wavelengths!



Credit: Robert Stein

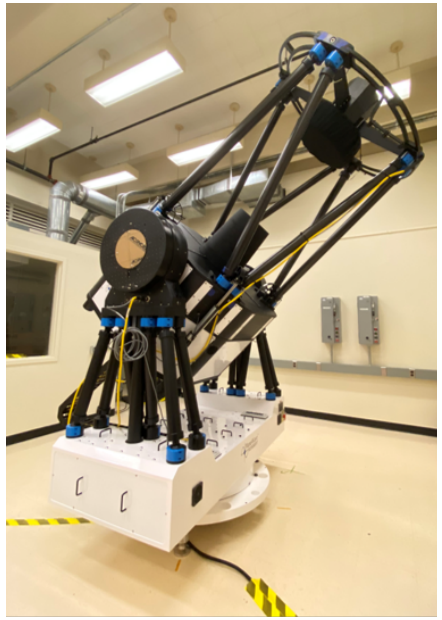
Introducing WINTER



J-band survey with ~monthly cadence

ToO program -> First dedicated IR neutrino follow-up program

Introducing WINTER



J-band survey with ~monthly cadence

ToO program -> First dedicated IR neutrino follow-up program

NIR is also great for kilonova searches ->
https://arxiv.org/abs/2110.01622

OPEN ACCESS

An Infrared Search for Kilonovae with the WINTER Telescope. I. Binary Neutron Star Mergers

Danielle Frostig[1], Sylvia Biscoveanu[1,2], Geoffrey Mo[1,2], Viraj Karambelkar[3], Tito Dal Canton[4], Hsin-Yu Chen[1,2], Mansi Kasliwal[3], Erik Katsavounidis[1,2], Nathan P. Lourie[1], Robert A. Simcoe[1] + Show full author list

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The Astrophysical Journal, Volume 926, Number 2

Citation Danielle Frostig *et al* 2022 *ApJ* **926** 152

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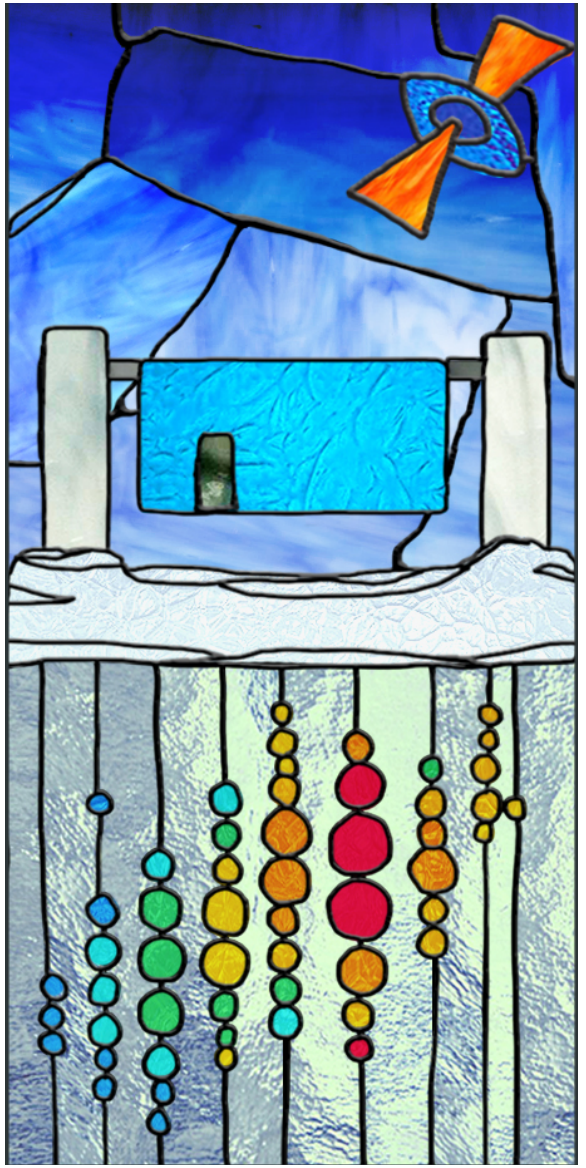
Summary

Summary

- IceCube discovered high-energy neutrinos, we are now trying to work out where they come from!
- ZTF neutrino follow-up program provided strong evidence that TDEs are one neutrino population. Now found 2 likely neutrino-TDEs.
- ZTF non-detections can be used to constrain optical properties of neutrino sources.
- Exciting science for WINTER with IR neutrino follow-up!

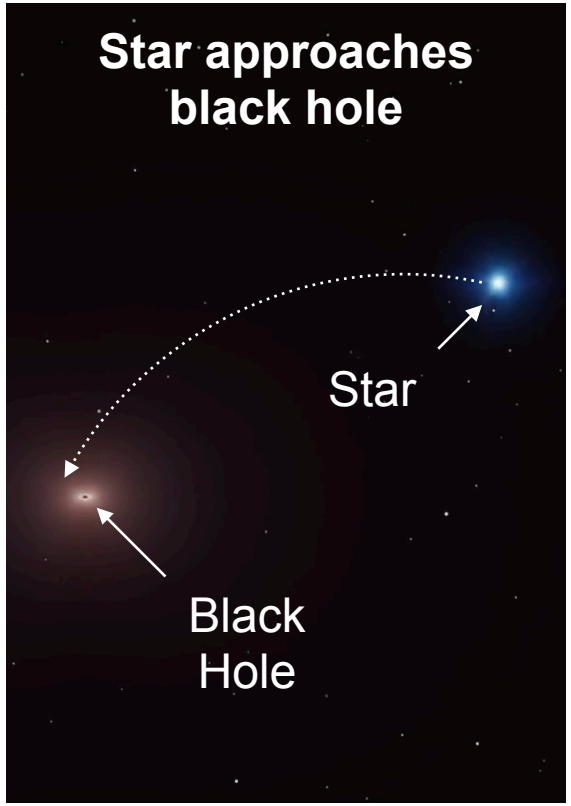


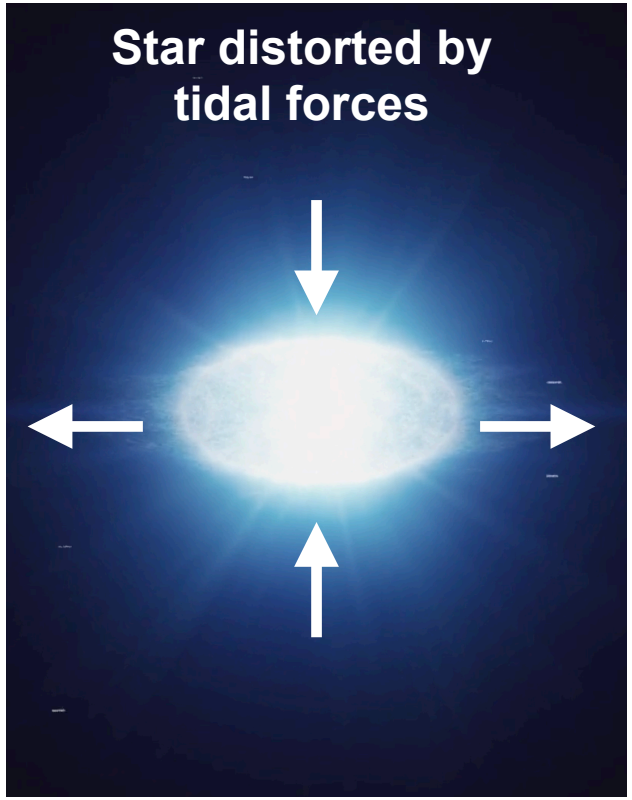
Credit: IceCube

Backup

What are TDEs?

Credit: DESY/Science communication Lab





1

2

3

4

Identifying AGN flares

Stein et al. 2022