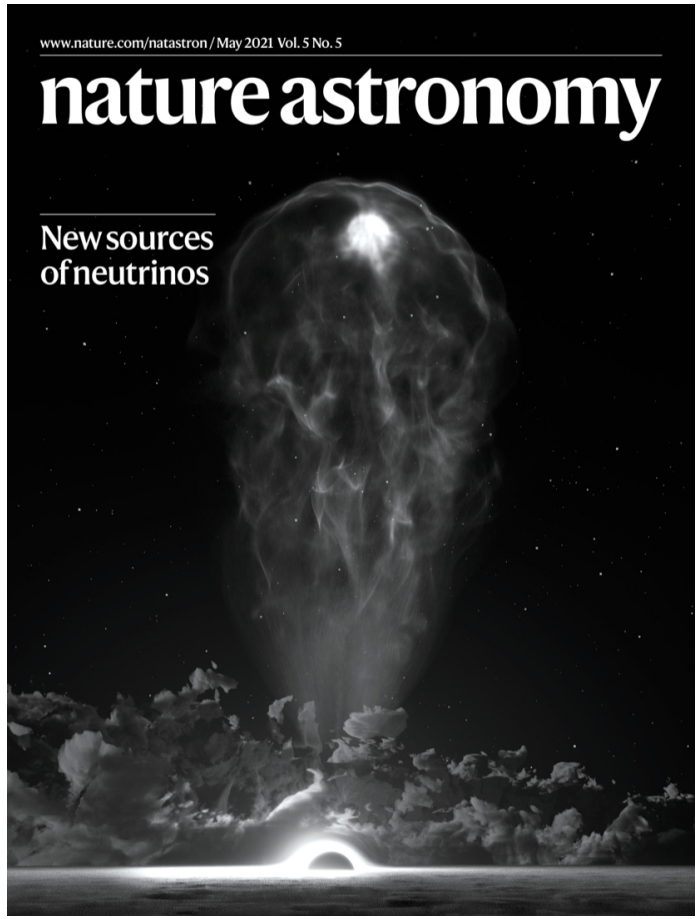
A Tidal Disruption Event coincident with a high-energy neutrino



Robert Stein ICRC 2021, 13/07/21

Robert Stein[*1,2], Sjoert van Velzen[*3,4], Marek Kowalski[*1,2,5], Anna Franckowiak[1,2], Suvi Gezari[4,6], James C. A. Miller-Jones[7], Sara Frederick[4], Itai Sfaradi[8], Michael F. Bietenholz[9,10], Assaf Horesh[8], Rob Fender[11,12], Simone Garrappa[1,2], Tomás Ahumada[4], Igor Andreoni[13], Justin Belicki[14], Eric C. Bellm[15], Markus Böttcher[16], Valery Brinnel[2], Rick Burruss[14], S. Bradley Cenko[6,17], Michael W. Coughlin[18], Virginia Cunningham[4], Andrew Drake[13], Glennys R. Farrar[3], Michael Feeney[14], Ryan J. Foley[19], Avishay Gal-Yam[20], V. Zach Golkhou[15,21], Ariel Goobar[22], Matthew J. Graham[13], Erica Hammerstein[4], George Helou[23], Tiara Hung[19], Mansi M. Kasliwal[13], Charles D. Kilpatrick[19], Albert K. H. Kong[24], Thomas Kupfer[25], Russ R. Laher[23], Ashish A. Mahabal[13,26], Frank J. Masci[23], Jannis Necker[1,2], Jakob Nordin[2], Daniel A. Perley[27], Mickael Rigault[28], Simeon Reusch[1,2], Hector Rodriguez[14], César Rojas-Bravo[19], Ben Rusholme[23], David L. Shupe[23], Leo P. Singer[17], Jesper Sollerman[29], Maayane T. Soumagnac[20,30], Daniel Stern[31], Kirsty Taggart[27], Jakob van Santen[1], Charlotte Ward[4], Patrick Woudt[12], Yuhan Yao[13]

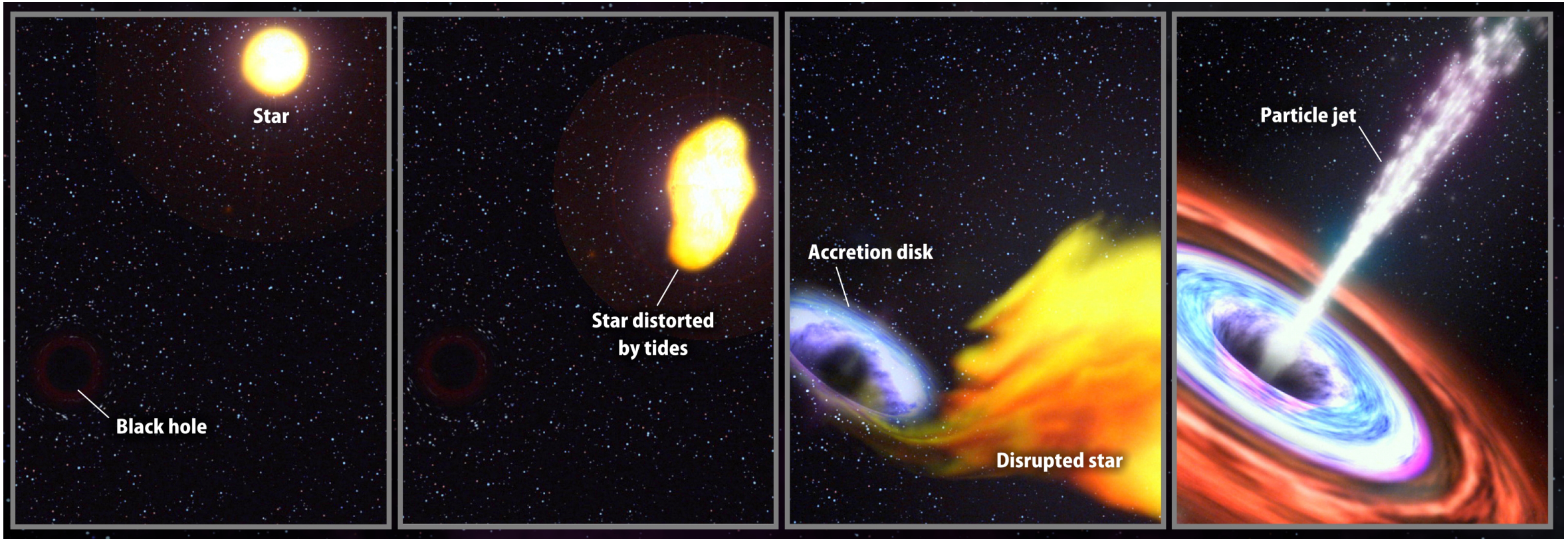
HELMHOLTZ
Young Investigators

ZTF

DESY.

Tidal Disruption Events

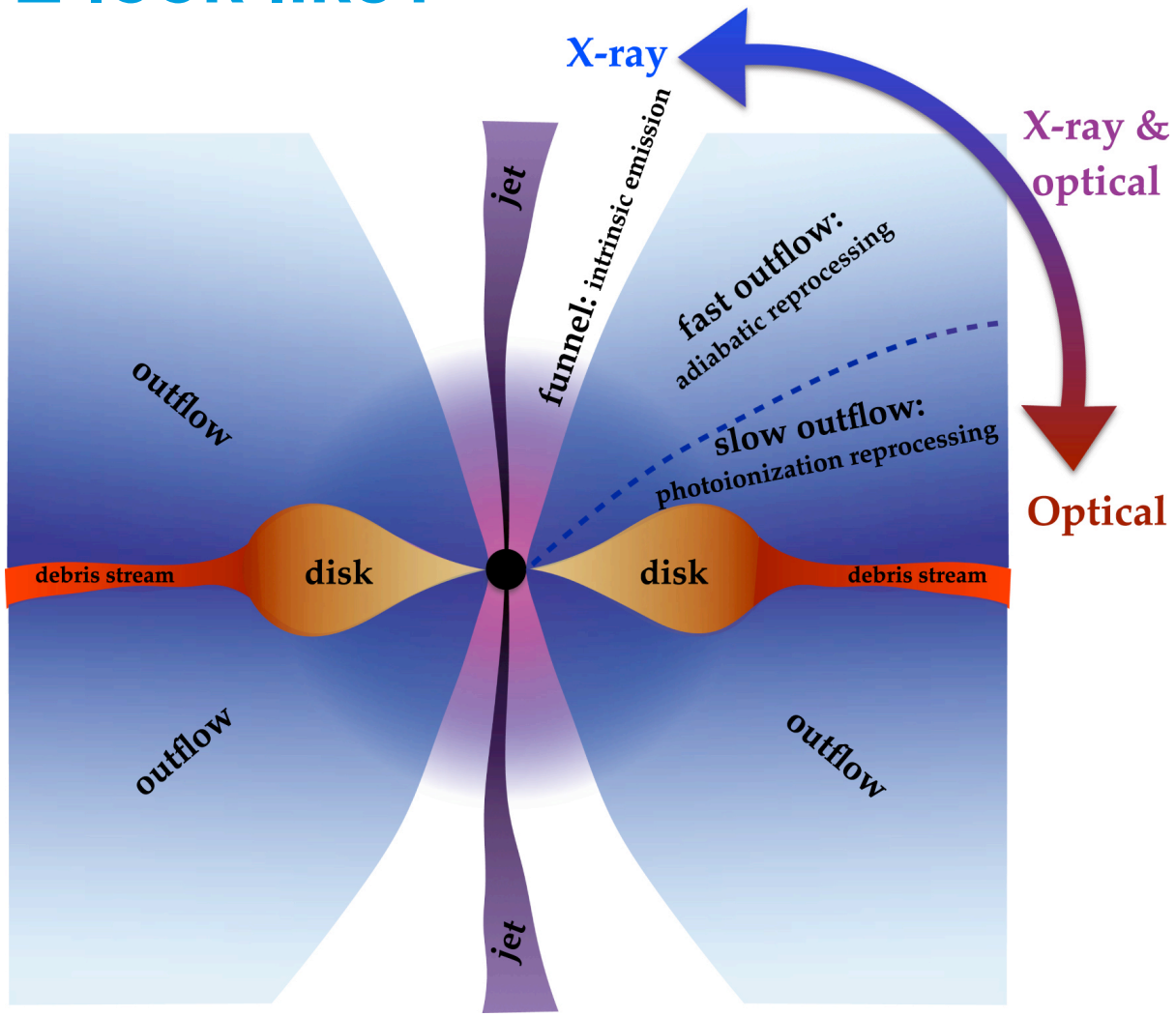
What are Tidal Disruption Events (TDEs)?



Credit: NASA

1 2 3 4

What does a TDE look like?

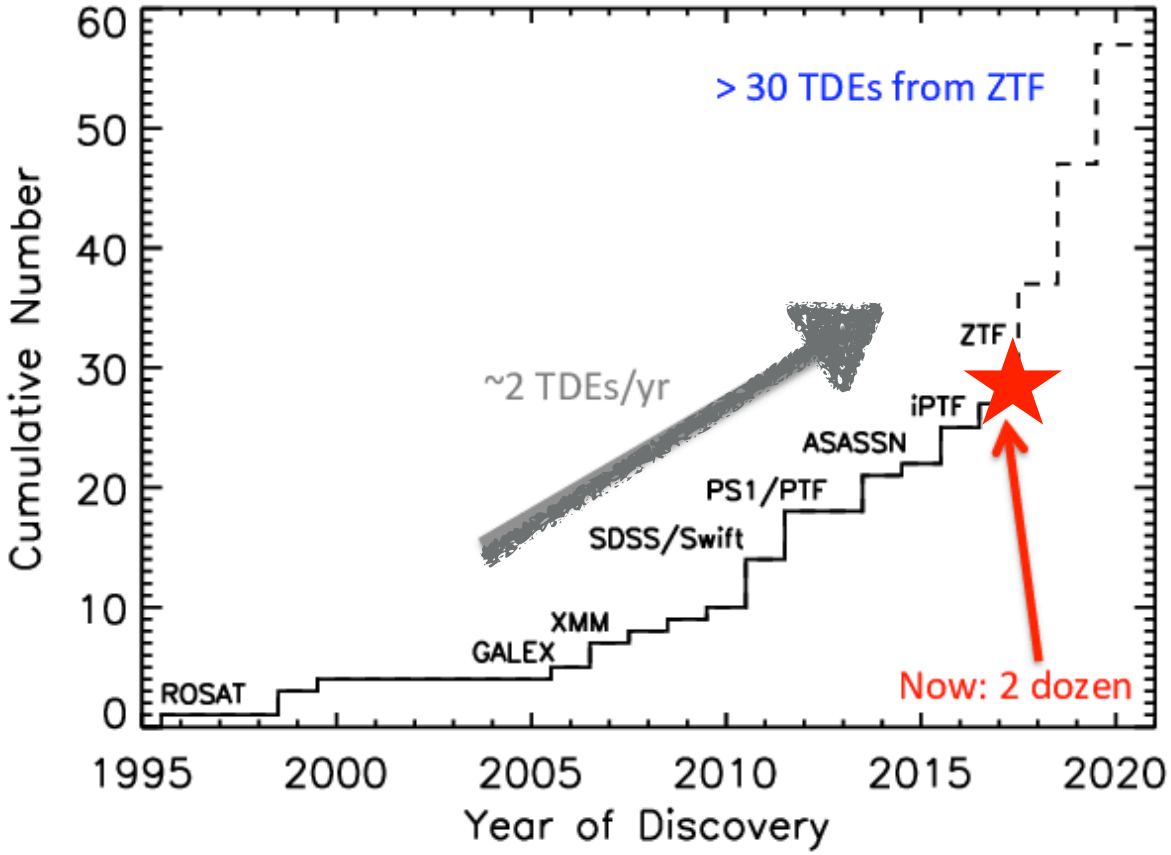


ApJ **859** L20 (2018)
Dai et al.

The TDE explosion…

The view from 2019:

- **~24 candidates across many observatories**
- **Sparse datasets with poor multi-wavelength coverage**
- **The future will be better**



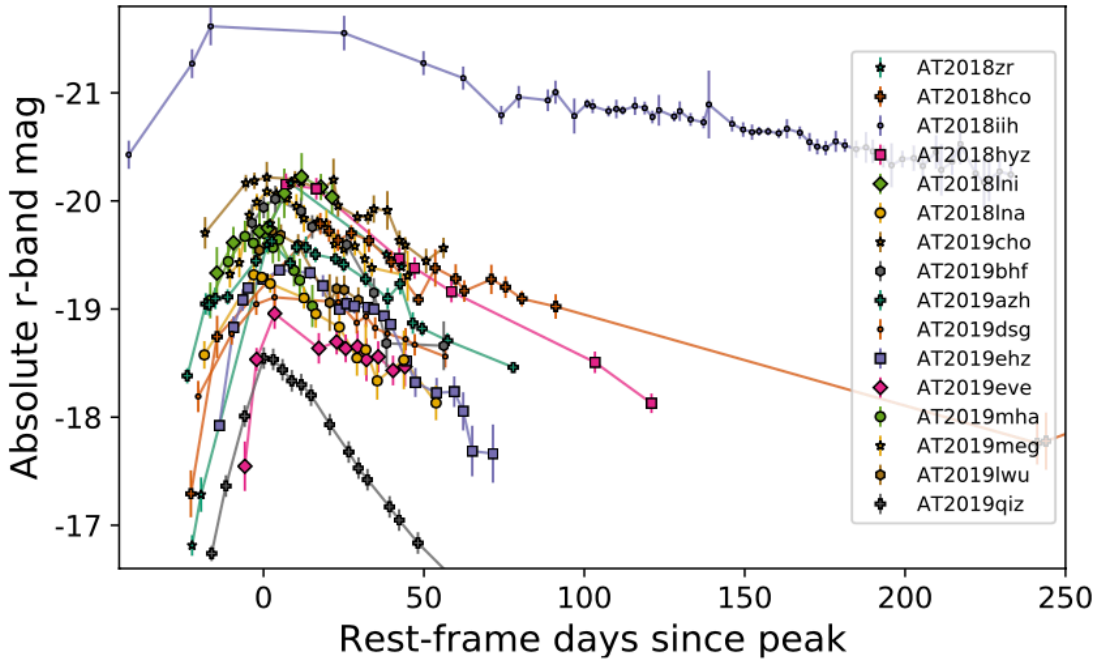
PASP **131** 078001 (2019)
Graham et al.

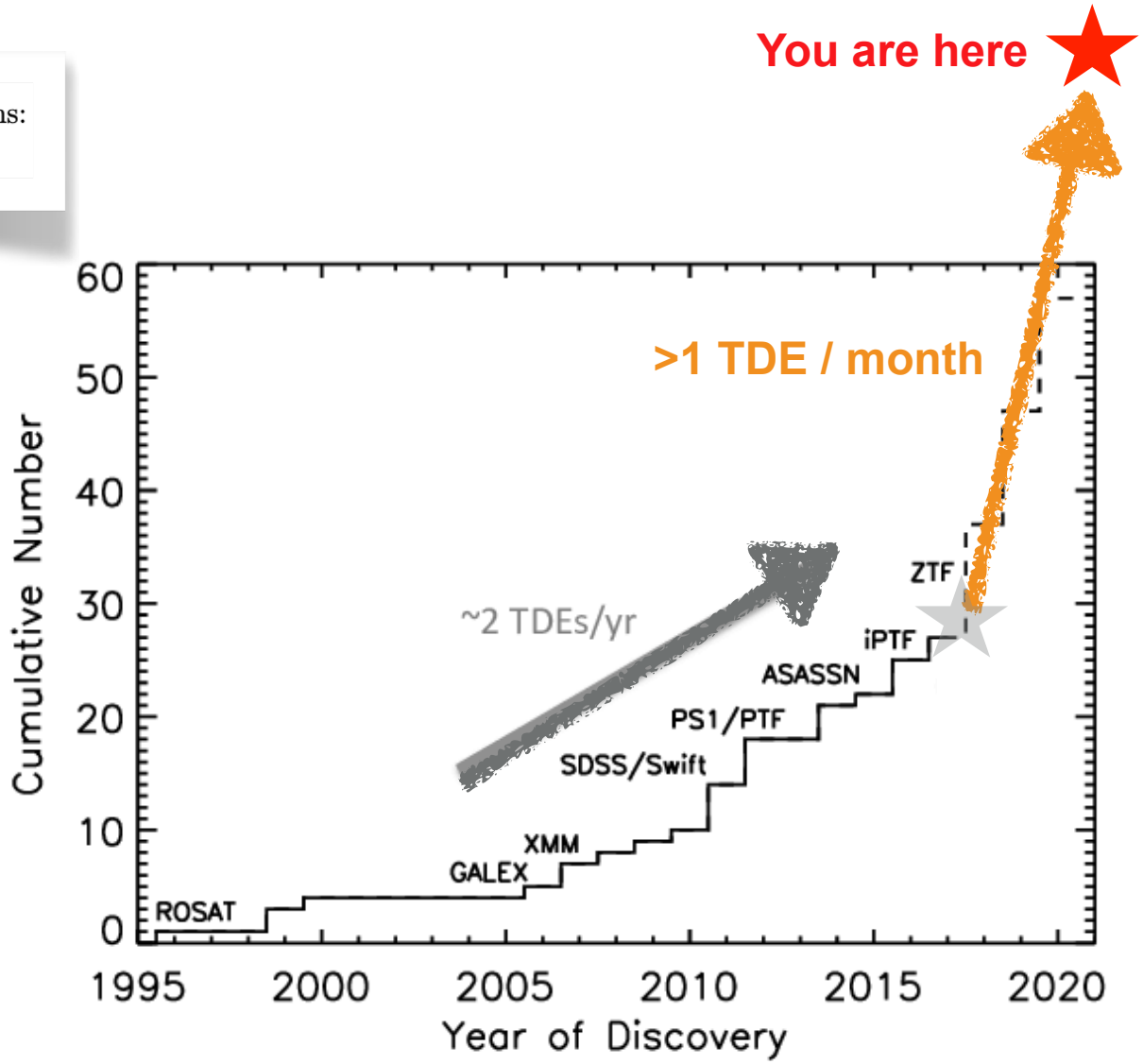
The TDE explosion…

Seventeen Tidal Disruption Events from the First Half of ZTF Survey Observations: Entering a New Era of Population Studies

ApJ **908** 4 (2021)
van Velzen et al.

The view from ~~2019~~ 2021:

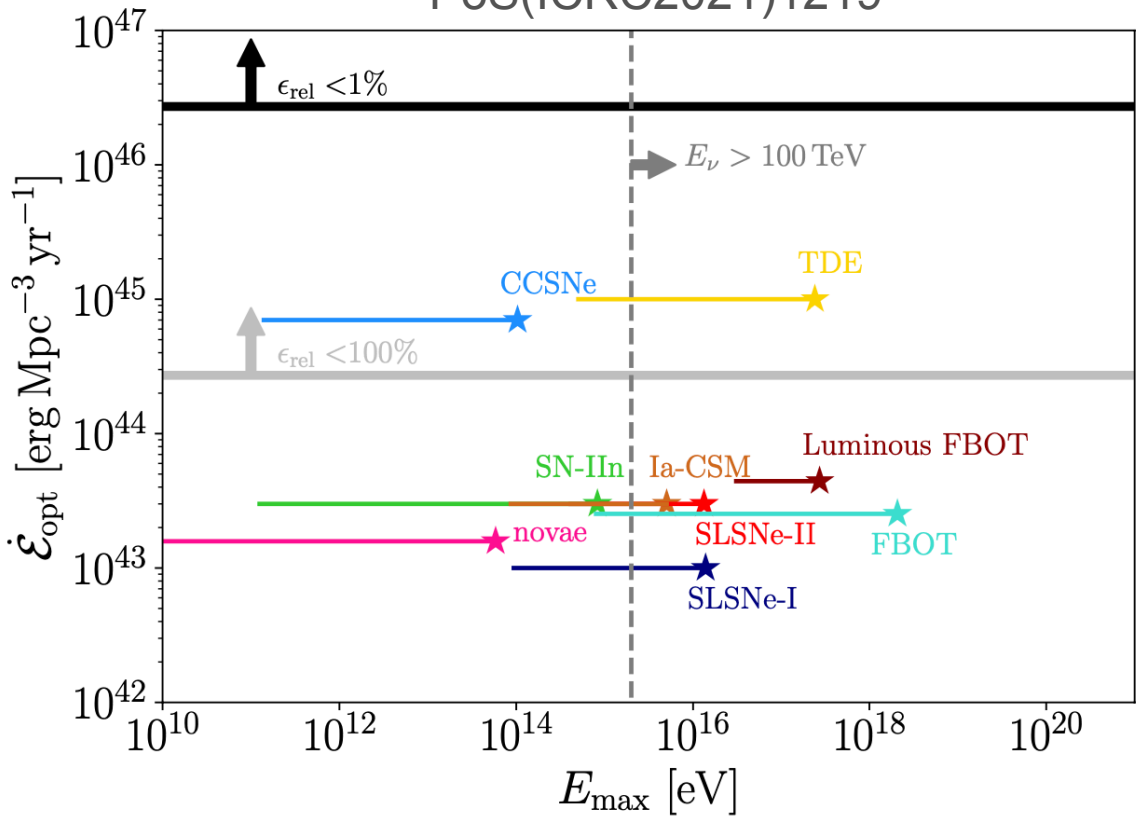




PASP **131** 078001 (2019)
Graham et al.

TDEs in the optical transient zoo

ApJ **904** 4 (2020)
Fang et al.
PoS(ICRC2021)1219

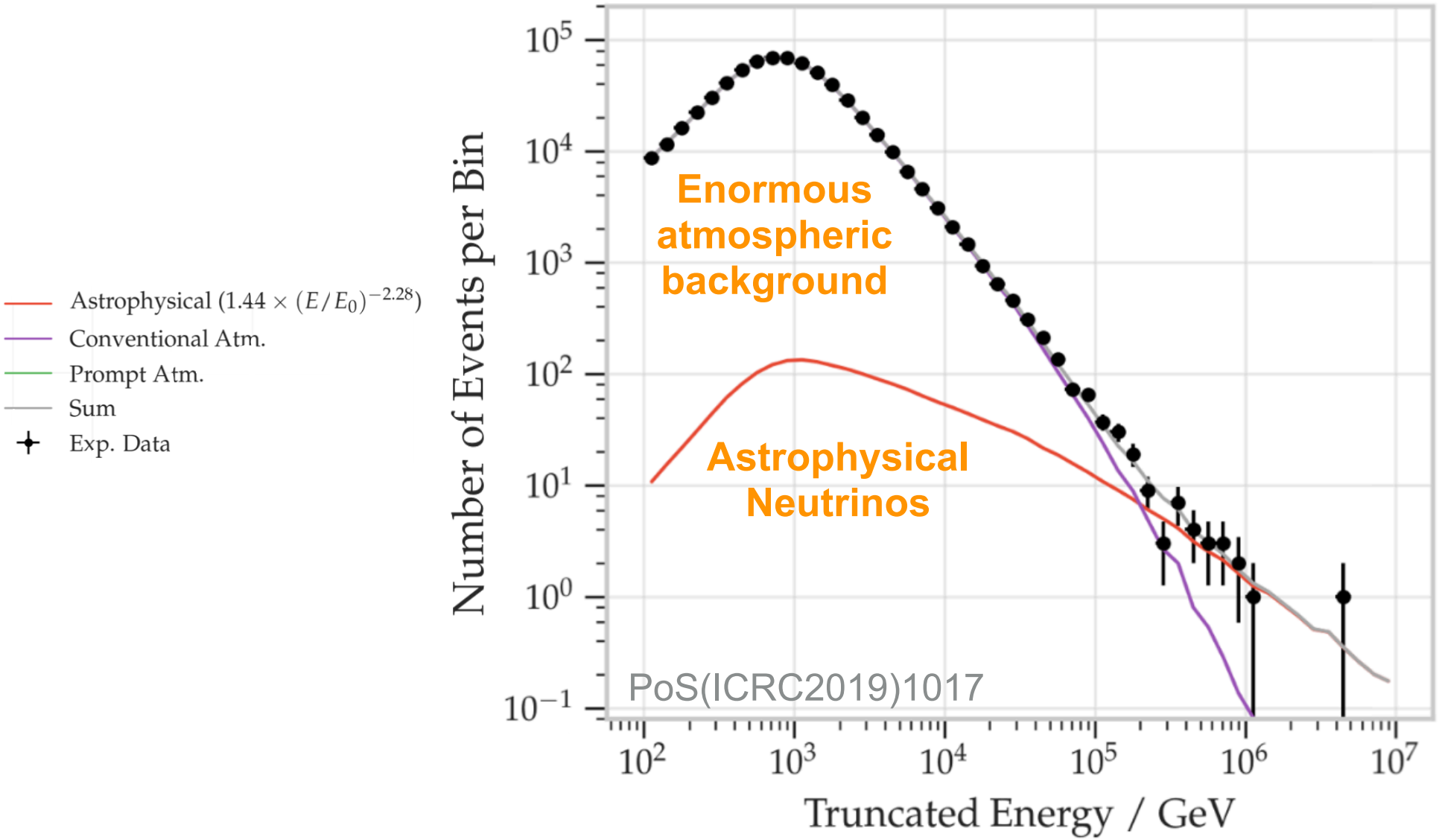


TDEs are one of the brightest known population of optical transients.

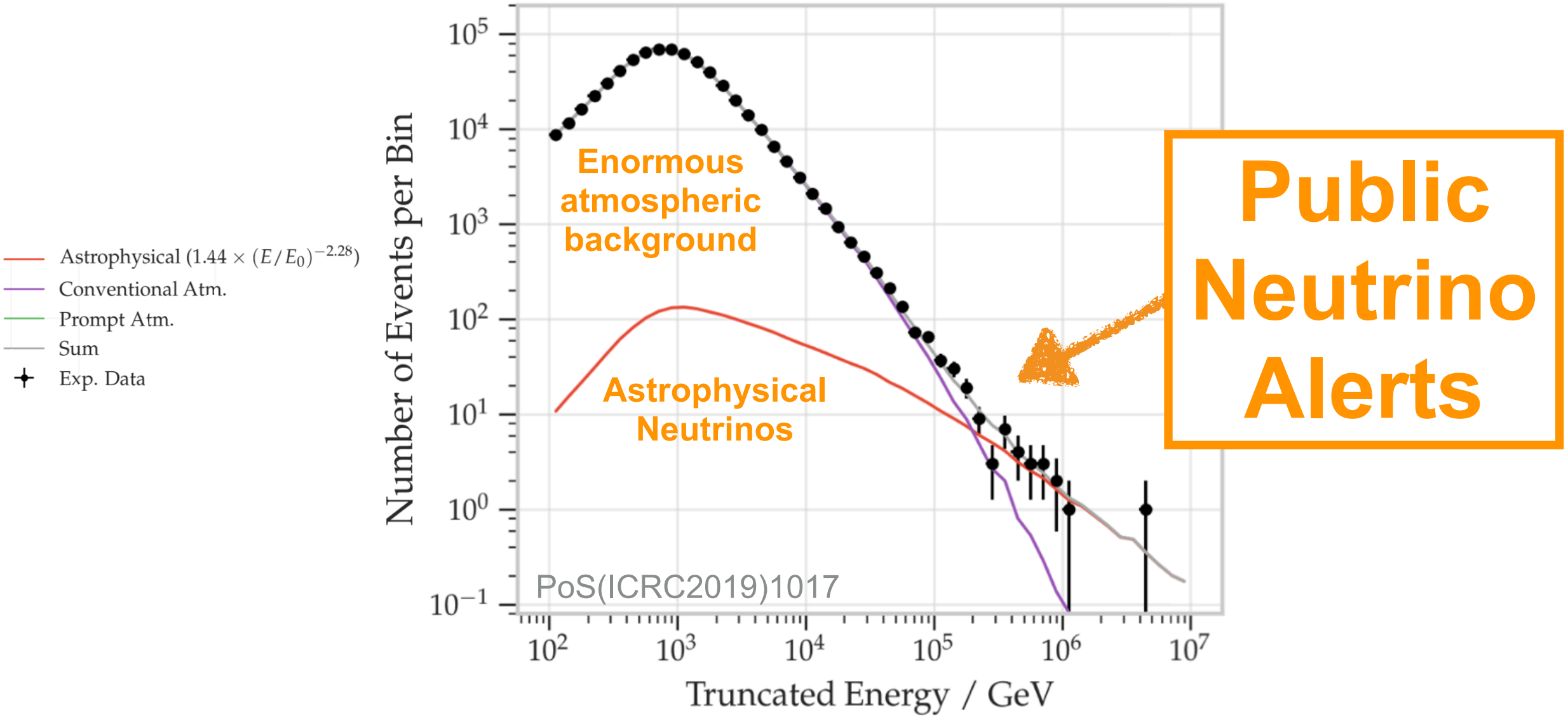
Even accounting for their low intrinsic rate, they output enormous energies.

High-energy neutrinos

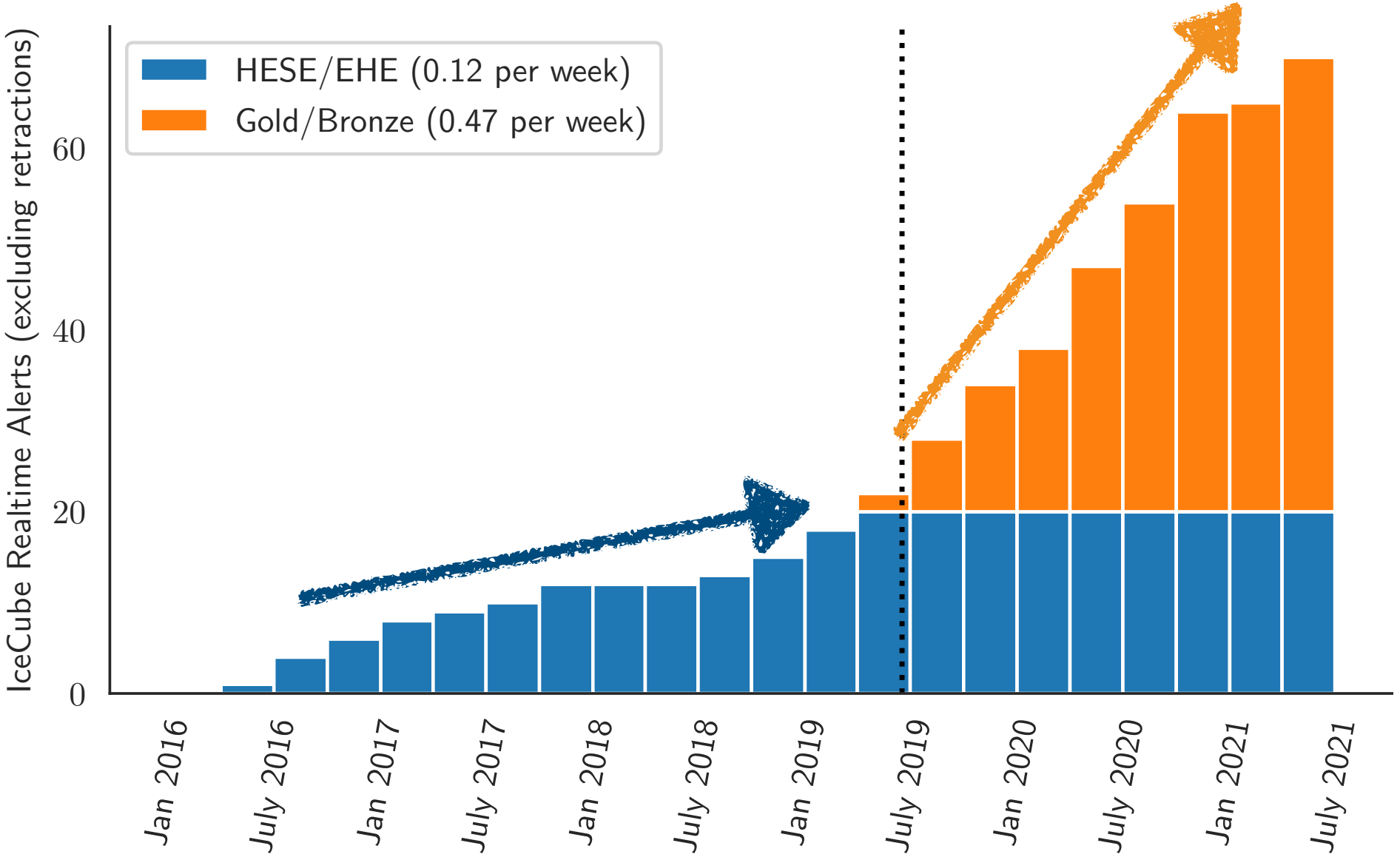
Neutrino Alerts in a nutshell



Neutrino Alerts in a nutshell



The public neutrino alert explosion

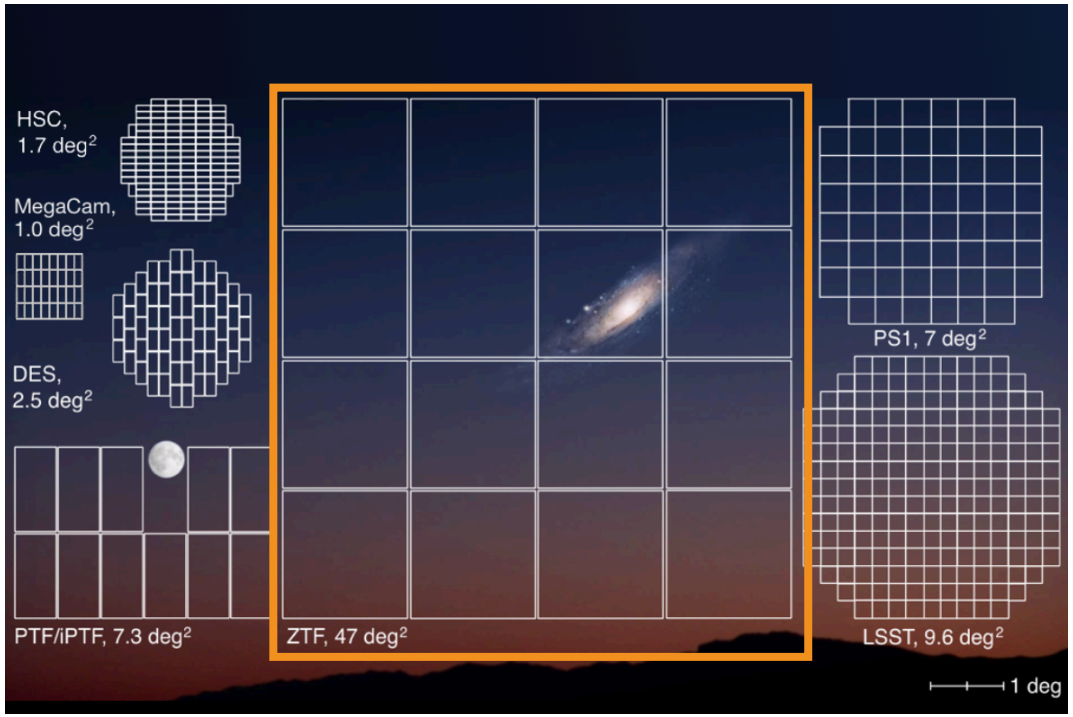


Zwicky Transient Facility

The Zwicky Transient Facility (ZTF)

Credit: Iair Arcavi

Credit: Joel Johansson



ZTF is an optical telescope with huge 47 sq. deg f.o.v. Optimised for volumetric survey speed.

Scans northern sky every 2 nights, to ~20.5 mag in g and r, as part of a public survey.

ZTF is an industrial transient discovery engine.

Transients in the ZTF era

>1500 CCSNe

>30 TDEs

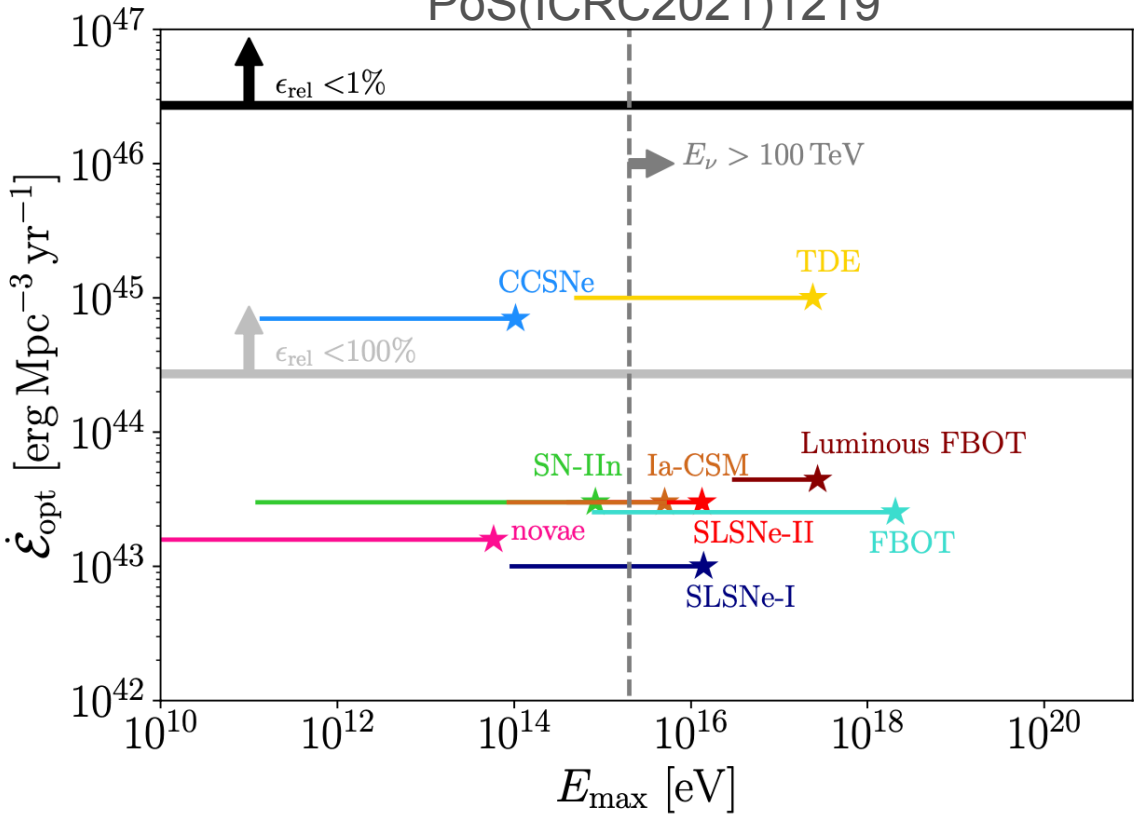
>130 SN-IIn

~3 FBOTs

~10 Ia-CSM

>100 SLSNe

ApJ **904** 4 (2020)
Fang et al.
PoS(ICRC2021)1219

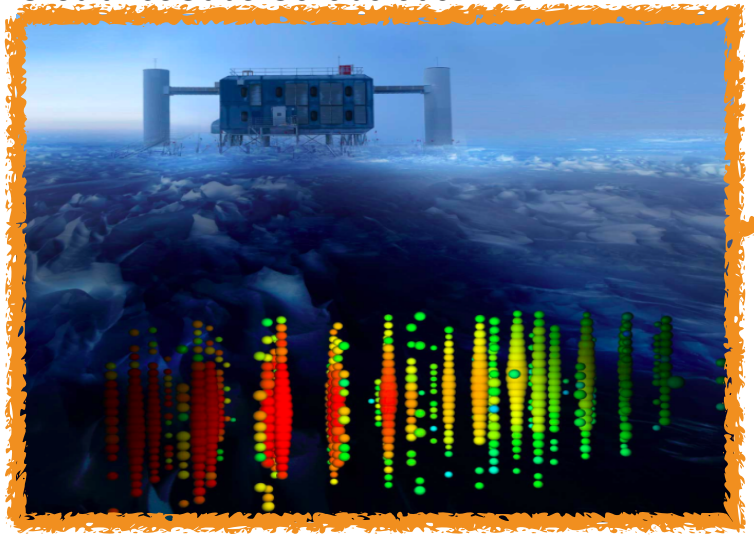


Combining messengers: the ZTF neutrino follow-up program

Credit: Iair Arcavi

~500k objects per night

Credit: IceCube Collaboration/NSF



Neutrino direction and time

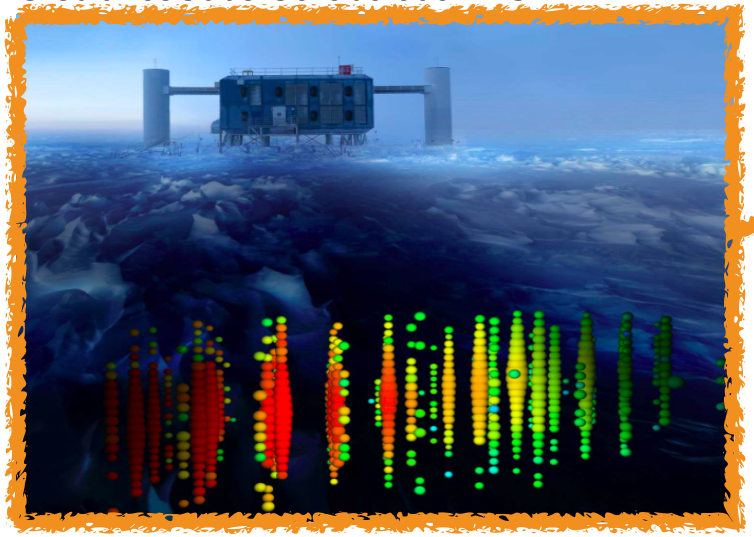
Find counterpart?

Combining messengers: the ZTF neutrino follow-up program

Credit: Iair Arcavi

~500k objects per night

Credit: IceCube Collaboration/NSF



Neutrino direction and time

Reject stars, asteroids, planets

Correlate

Spectroscopically classify few remaining objects

Find counterpart?

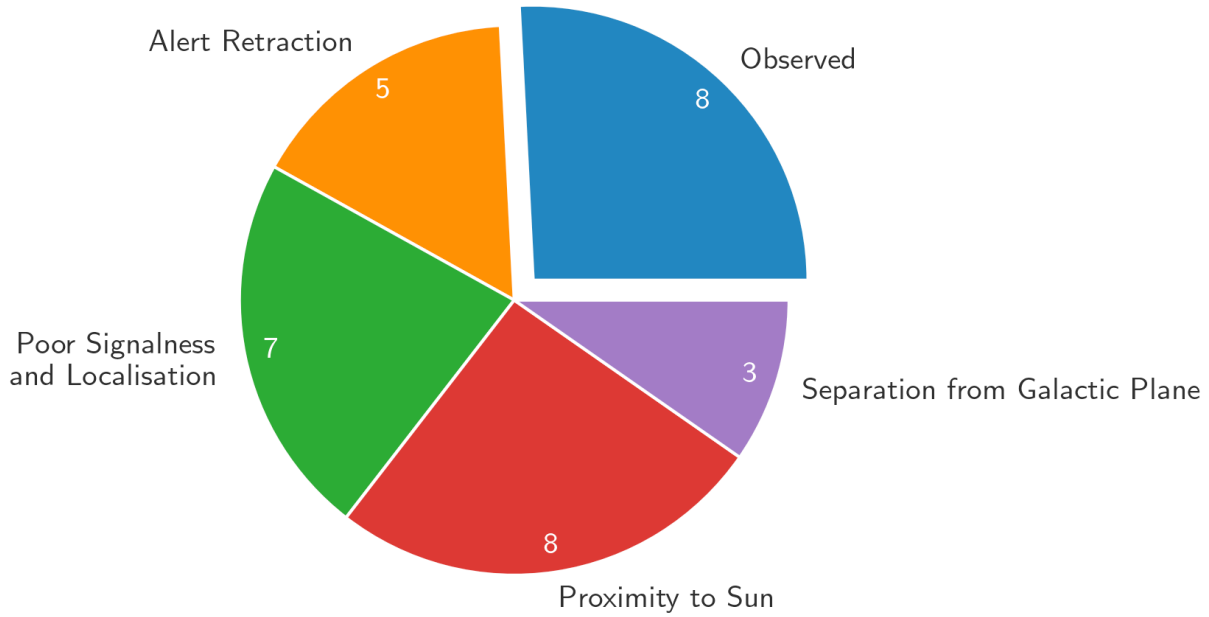
ZTF neutrino follow-up program

8/31 alerts followed-up

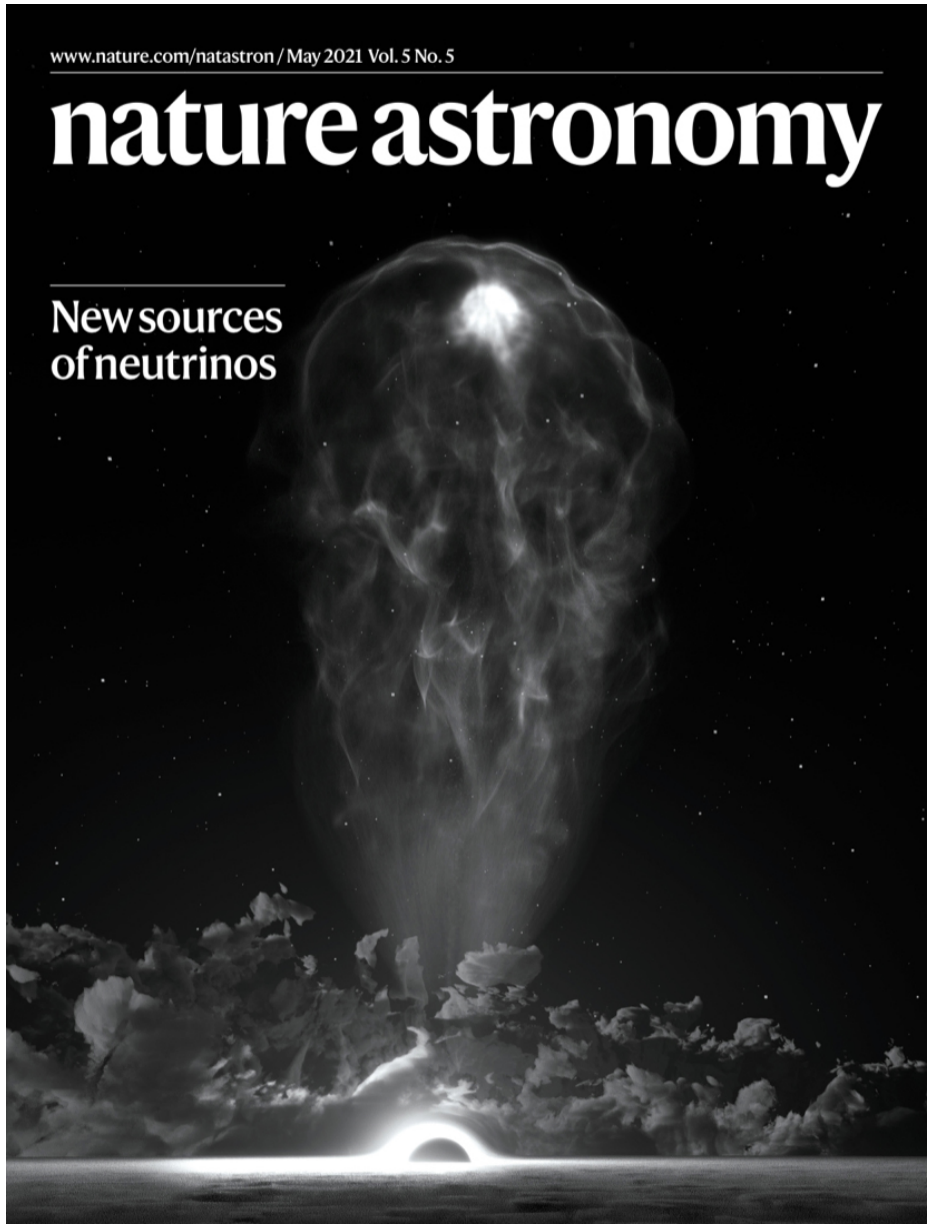
Event	R.A (deg)	Dec (deg)	90% area (sq. deg.)	ZTF obs (sq. deg.)	Signalness	Ref
IC190503A	120.28	+6.35	1.94	1.37	36%	40,41
IC190619A	343.26	+10.73	27.16	21.57	55%	42,43
IC190730A	225.79	+10.47	5.41	4.52	67%	44,45
IC190922B	5.76	-1.57	4.48	4.09	51%	46–48
IC191001A	**314.08**	**+12.94**	**25.53**	**20.56**	**59%**	**11,15,49**
IC200107A	148.18	+35.46	7.62	6.22	-	39,50
IC200109A	164.49	+11.87	22.52	20.06	77%	51,52
IC200117A	116.24	+29.14	2.86	2.66	38%	53–55

Table 1: Summary of the eight neutrino alerts followed up by ZTF, with IC191001A highlighted in bold. The area column indicates the region of sky observed at least twice by ZTF, within the reported 90% localisation, and accounting for chip gaps. The *signalness* describes the probability that each neutrino is of astrophysical origin, rather than arising from atmospheric backgrounds. One alert, IC200107A, was reported without a signalness estimate.

23/31 alerts not followed-up



As of Feb 2020, ZTF had (conditions-permitting) followed up every accessible alert since March 2018, except those low-quality alerts with both signalness < 50% and 90% area > 10 sq. deg.



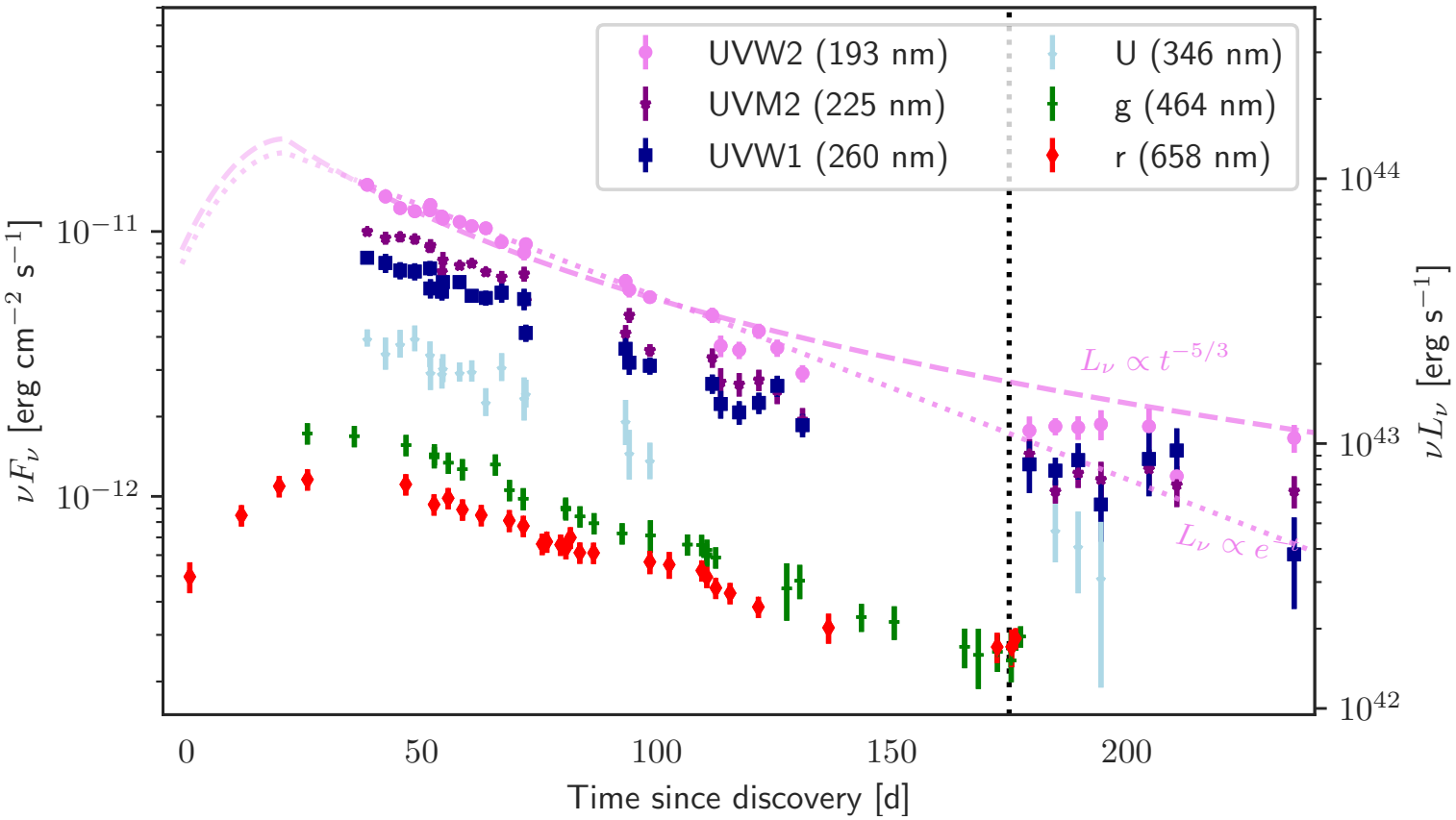
ARTICLES
https://doi.org/10.1038/s41550-020-01295-8
nature astronomy

A tidal disruption event coincident with a high-energy neutrino

Credit: DESY/Science Communication Lab/Nature Astronomy

AT2019dsg

Introducing AT2019dsg

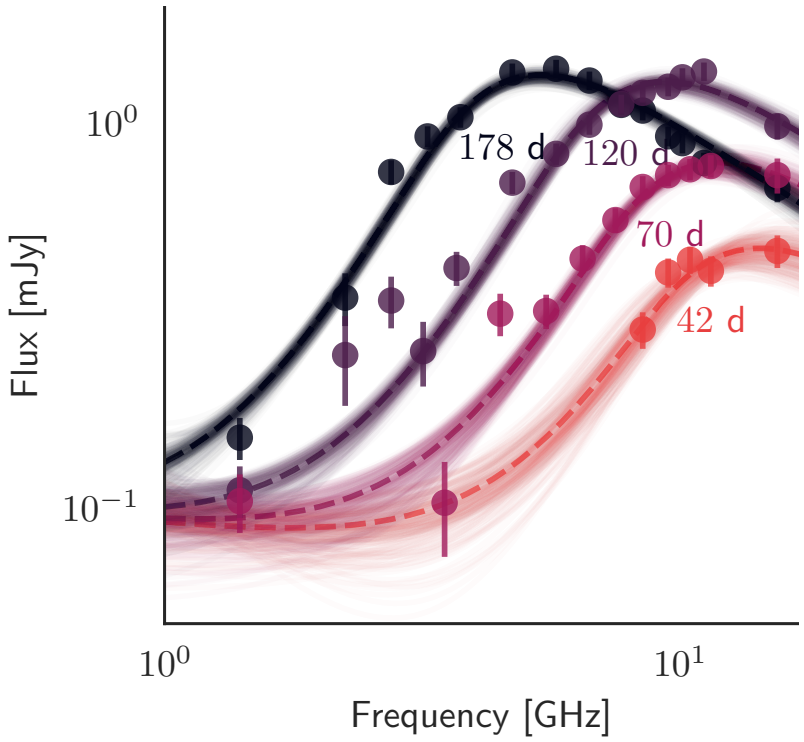


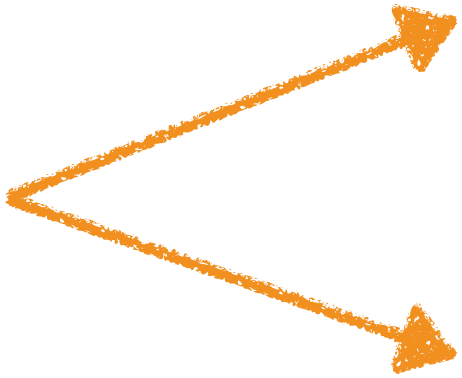
Discovered in April 2019 by ZTF, lots of data! Neutrino arrived ~175 days post-discovery.

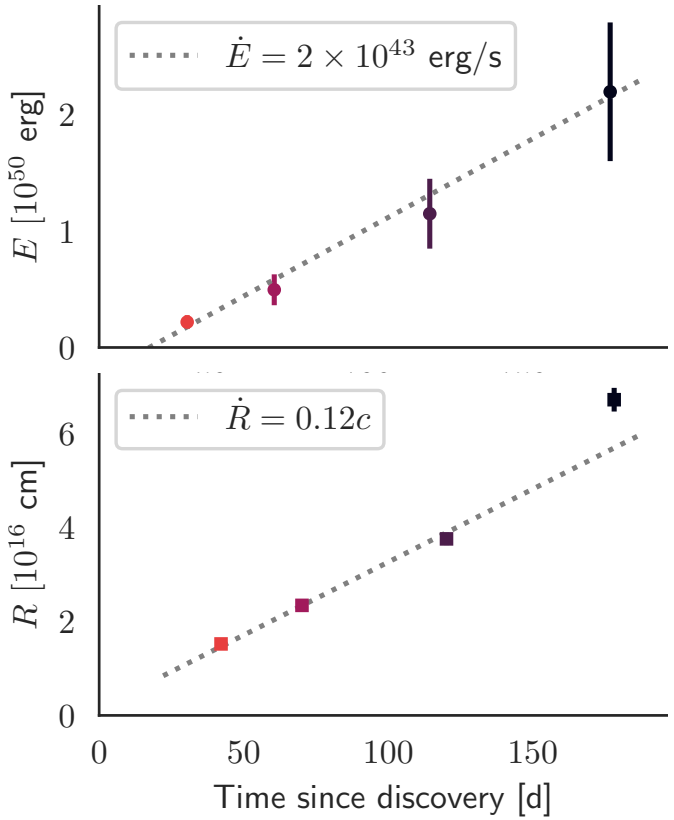
As for most TDEs, well-described by thermal emission ($T \sim 10^{4.6}$ K, $R \sim 10^{14.5}$ cm, $L_{peak} \sim 10^{44.5}$ erg s^{-1})

Pretty hot (lots of UV emission), and very bright in terms of bolometric flux

Long-lived non-thermal emission from an outflow





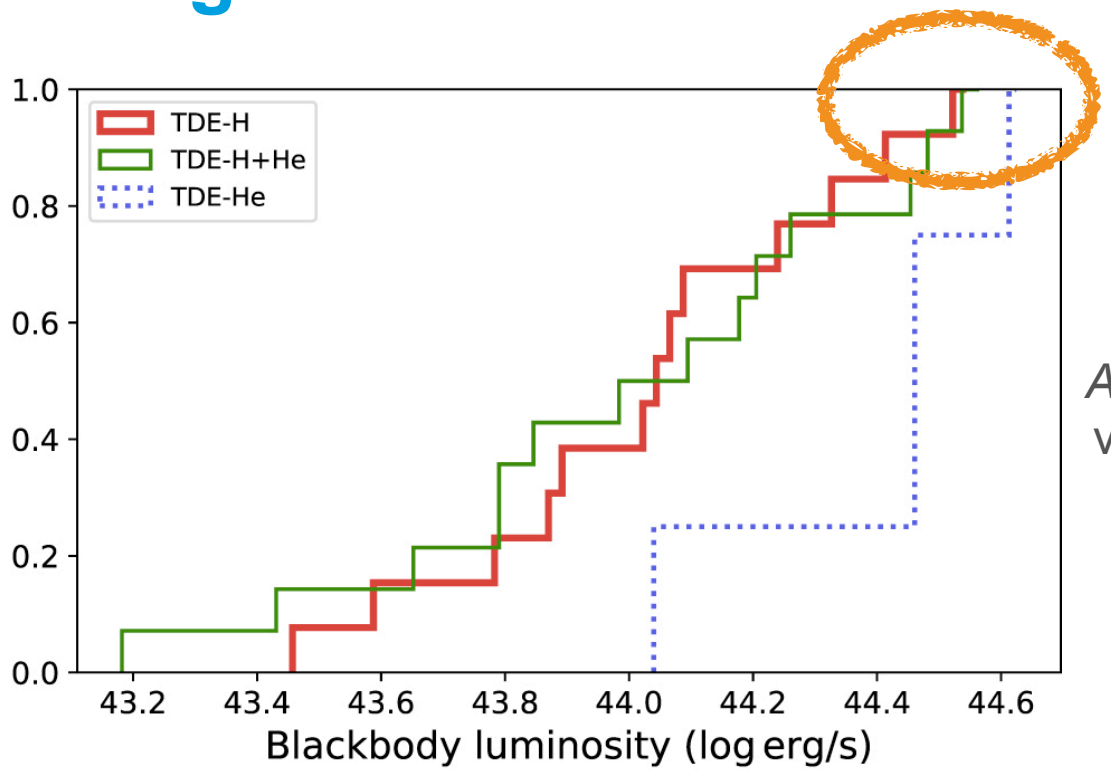


Radio analysis reveals extended synchrotron-emitting outflow

Expands ~10^{16} cm to ~10^{17}cm, with evidence for late-time acceleration.

Inferred energy in outflow increases (~linearly) in each epoch to ~2 x10^{50} ergs

IC191001A + AT2019dsg



ApJ **908** 4 (2021)
van Velzen et al.

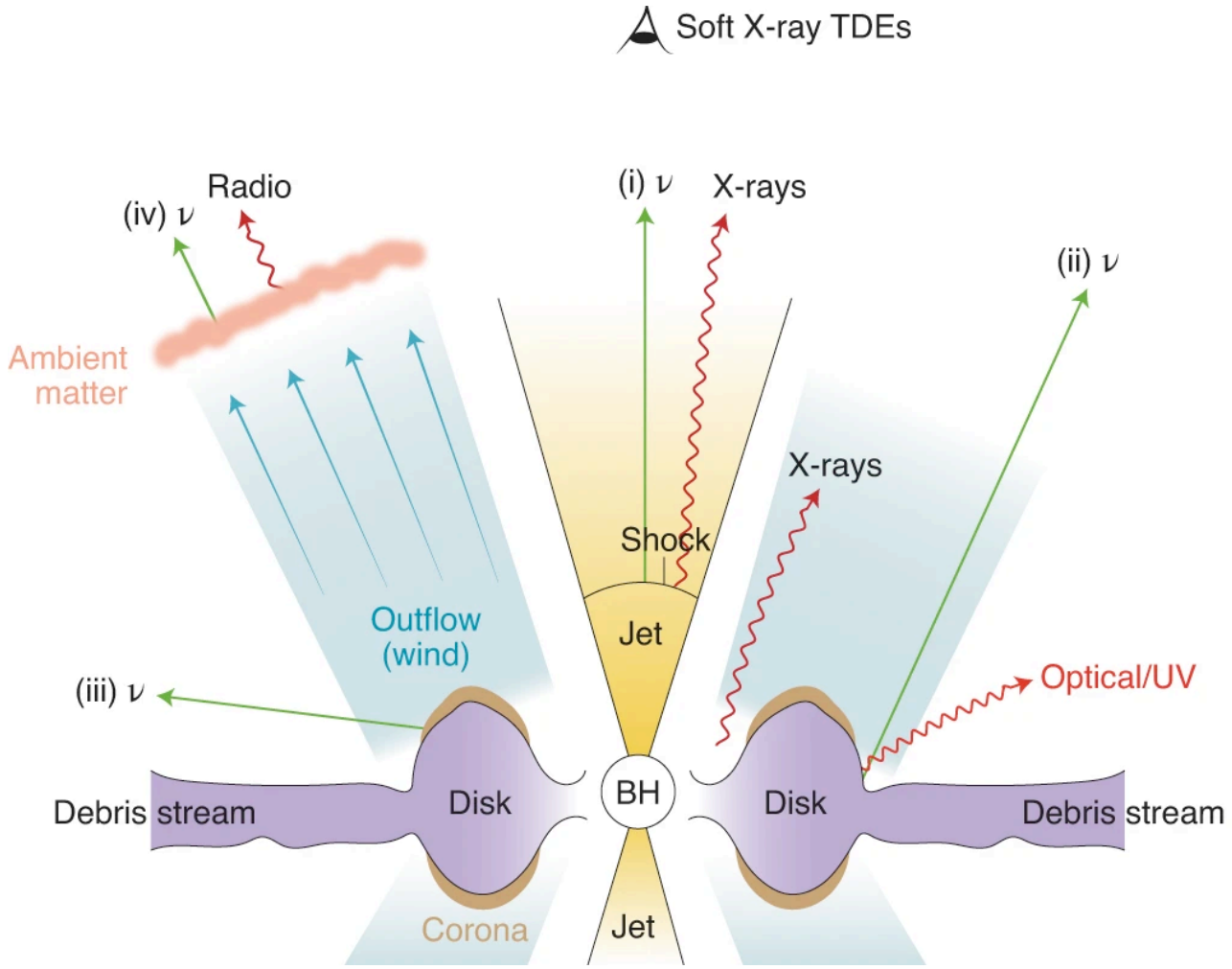
TDEs have been previously highlighted as promising neutrino sources, so targeted by our program.

AT2019dsg detected with radio emission (evidence of particle acceleration), so even more promising.

TDEs are still rare. AT2019dsg is the second brightest ZTF TDE, as measured by bolometric energy flux (top 10%). Probability to find a TDE so bright is just 0.2%.

Neutrinos from Tidal Disruption Events

Neutrinos from Tidal Disruption Events



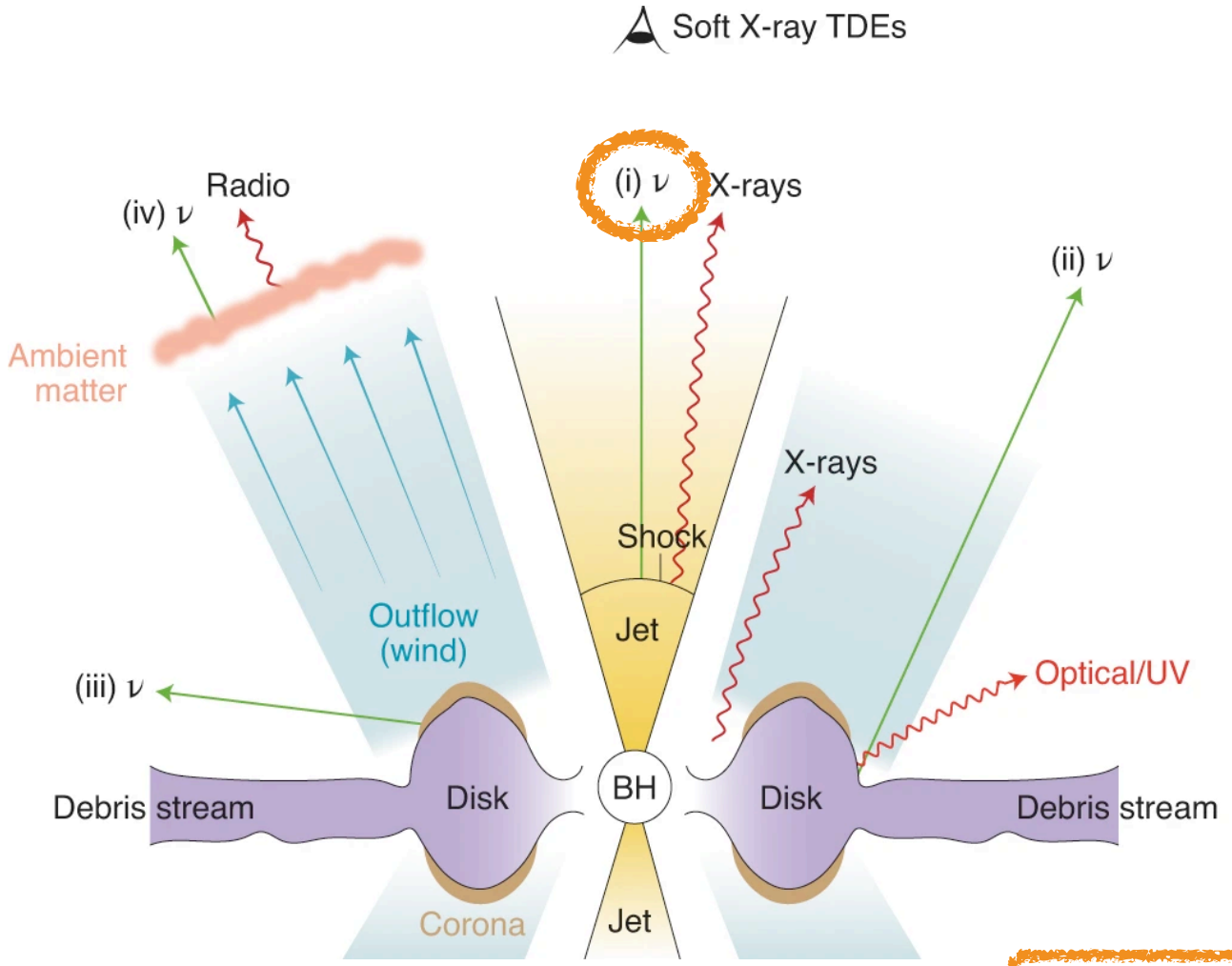
Nat Astron **5** 436–437 (2021)
Hayasaki

Suggested neutrino production zones include:

i. Relativistic Jets
ii. The accretion disk
iii. The disk corona
iv. The wind/outflow

Optical/UV TDEs

Neutrinos from Tidal Disruption Events



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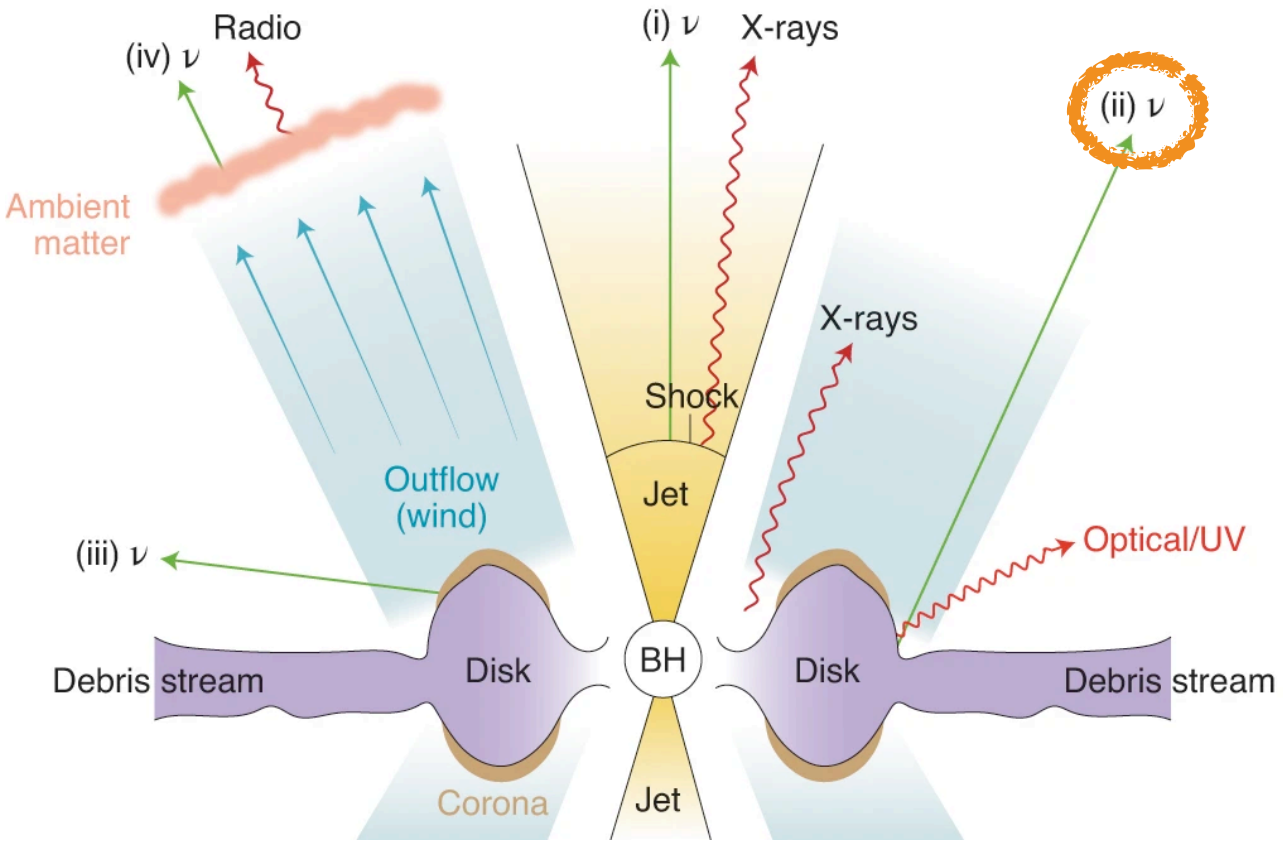
Nat. Astron. **5** 472-477 (2021)
Winter & Lunardini
PoS(ICRC2021)997

Phys. Rev. D **102**, 083028 (2020)
Liu, Xi & Wang

Neutrinos from Tidal Disruption Events

Soft X-ray TDEs



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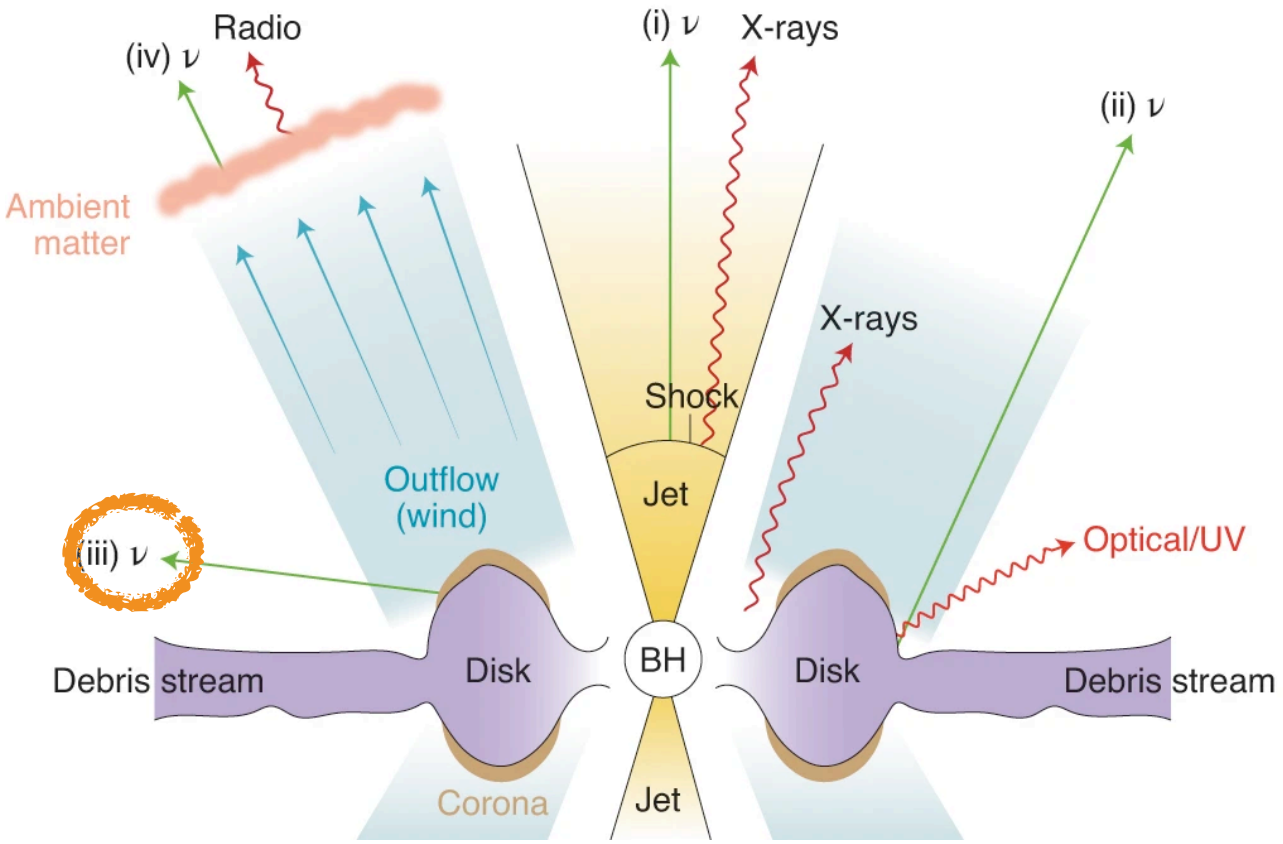
Optical/UV TDEs

Astrophys.J. **886** 114 (2019)
Hayasaki & Yamazaki

Neutrinos from Tidal Disruption Events

Soft X-ray TDEs



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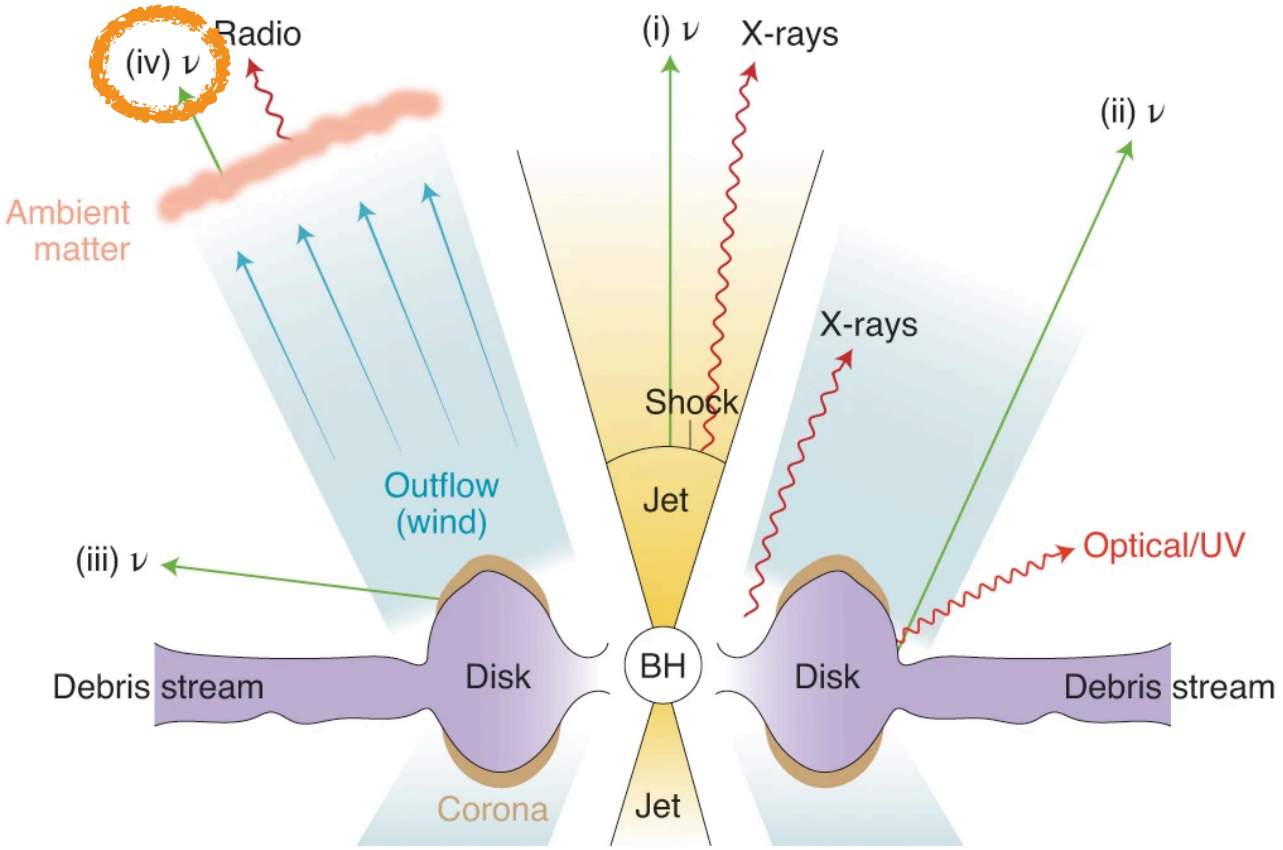
Optical/UV TDEs

Astrophys.J. **902** 108 (2020)
Murase, Kimura, Zhang, Oikonomou & Petropoulou

Neutrinos from Tidal Disruption Events

Soft X-ray TDEs



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Optical/UV TDEs

Astrophys.J. **902** 108 (2020)
Murase, Kimura, Zhang, Oikonomou & Petropoulou

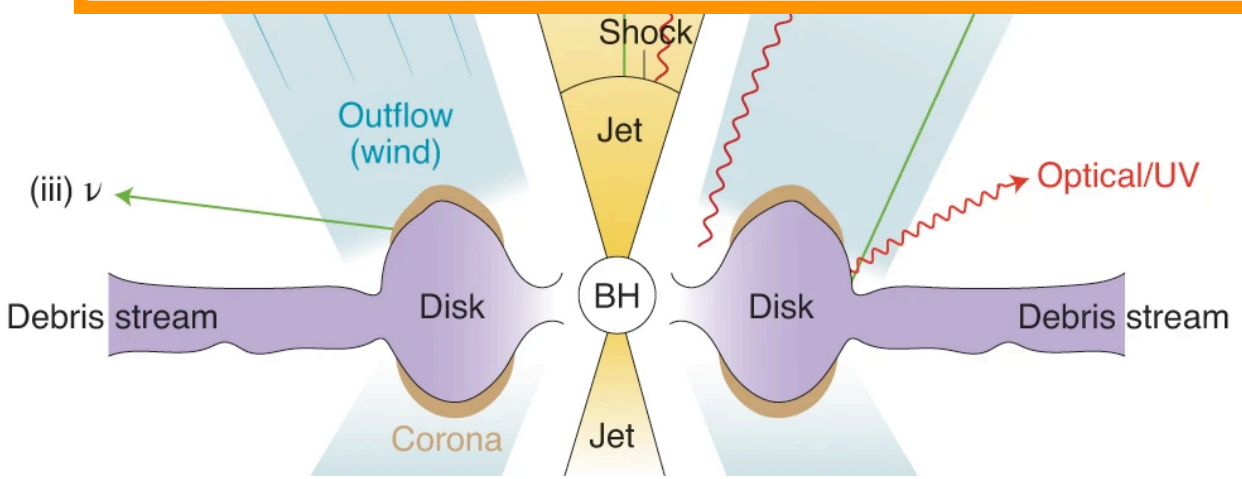
Neutrinos from Tidal Disruption Events

Soft X-ray TDEs

Conditions appear consistent with requirements for ~PeV neutrino production/detection

Ambien
matte

iv. The wind/outflow



Nat Astron **5** 436–437 (2021)
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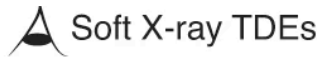
Optical/UV TDEs

Astrophys.J. **902** 108 (2020)
Murase, Kimura, Zhang, Oikonomou & Petropoulou

Neutrinos from Tidal Disruption Events



Conditions appear consistent with requirements for ~PeV neutrino production/detection

Association suggests TDEs contribute at least 2% of the neutrino flux. Leaves a lot of "unknown".

Nat Astron **5** 436–437 (2021)
Hayasaki

Oikonomou & Petropoulou

AT2019dsg neutrino searches reported by ANTARES and Baikal-GVD

PoS(ICRC2021)1161
Illuminati et al.

PoS(ICRC2021)946
Suvorova et al.

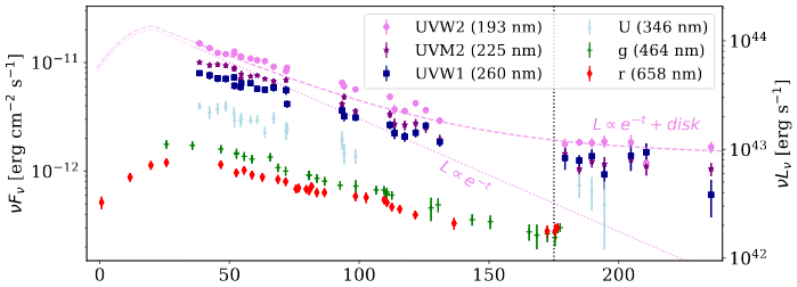
BAIKAL-GVD

No significant neutrino excess reported by ANTARES in the TeV-PeV range, but neutrino predictions lie below the ANTARES sensitivity.

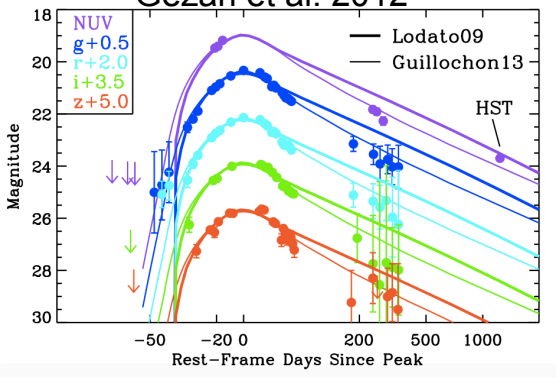
Baikal-GVD reported preliminary indications of a possible excess, but analysis still ongoing.

See contribution #1161 and #946 for more details!

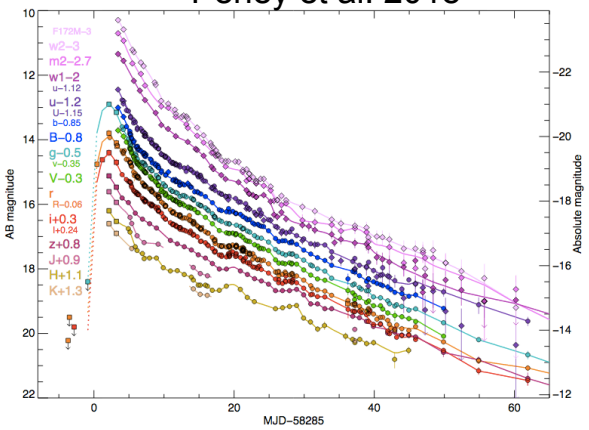
How special is AT2019dsg? An Eddington bias problem…

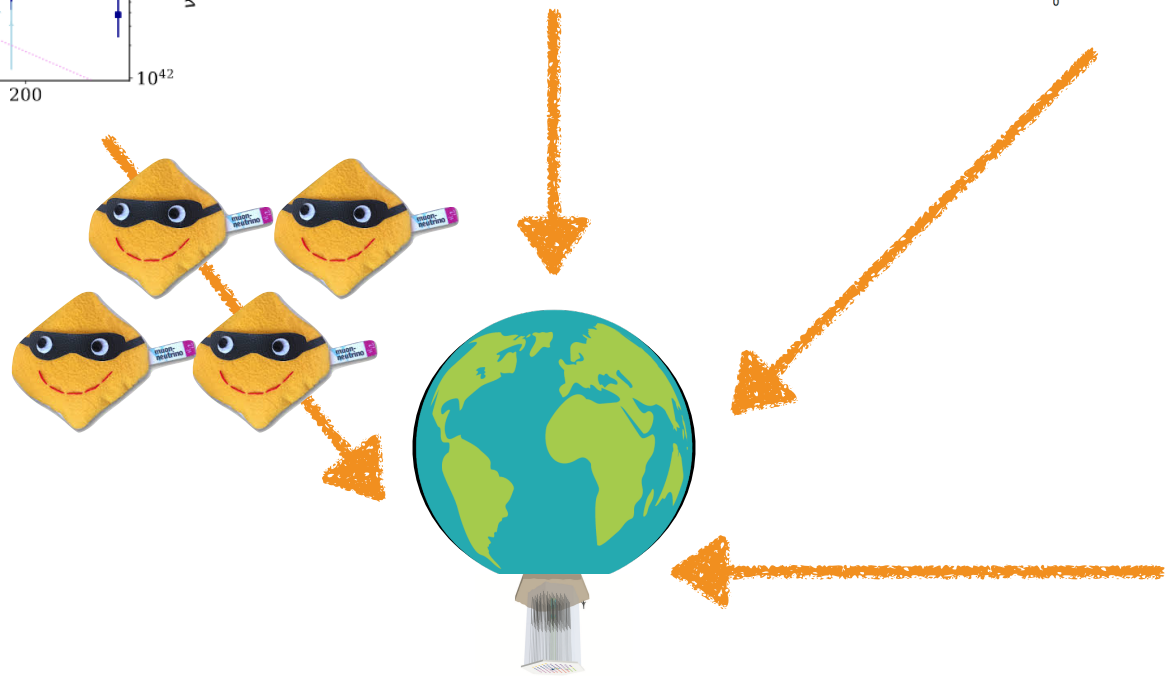


Gezari et al. 2012

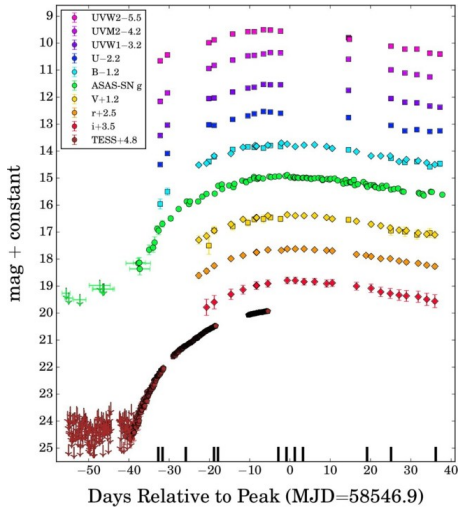


Perley et al. 2018





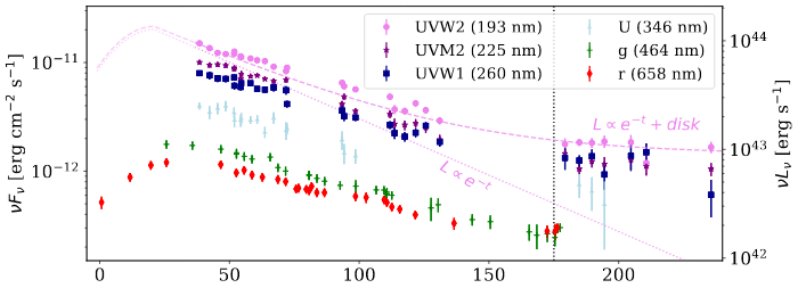
Holoien et al. 2018

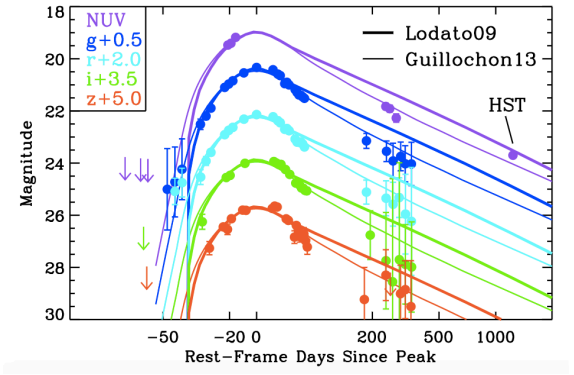


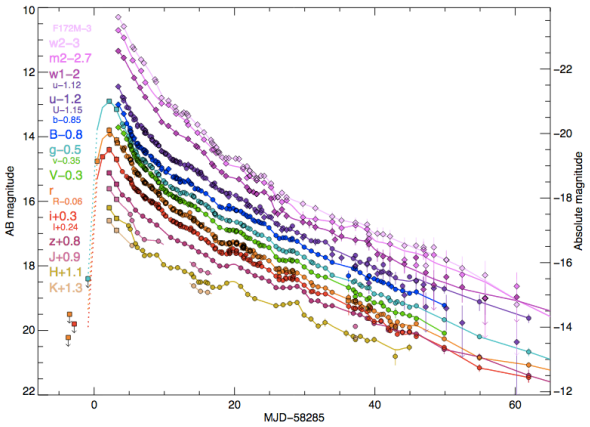
A&A **622**, L9 (2019)
Strotjohann et al.

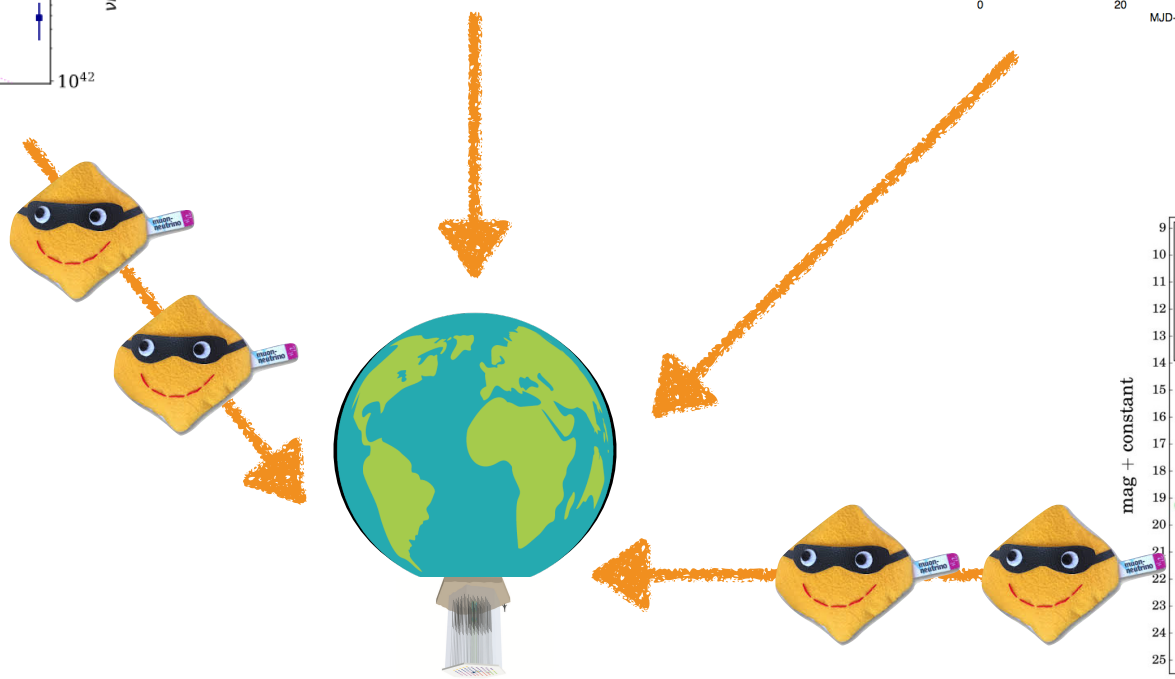
Credit: ParticleZoo/IceCube/YouthEarthWeek

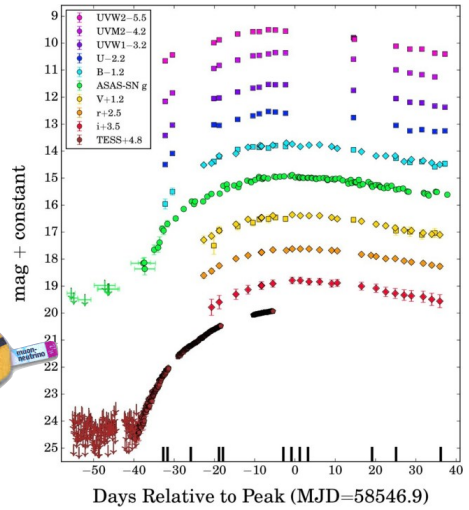
How special is AT2019dsg? An Eddington bias problem…





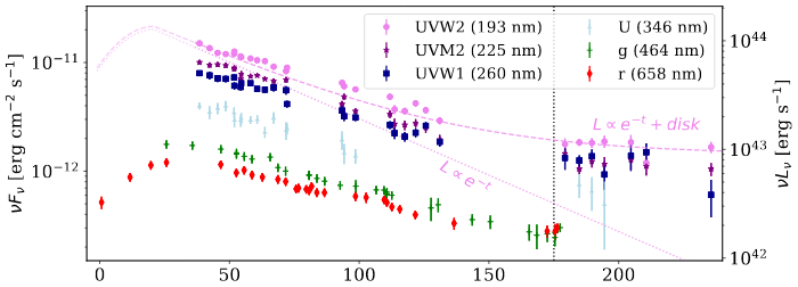


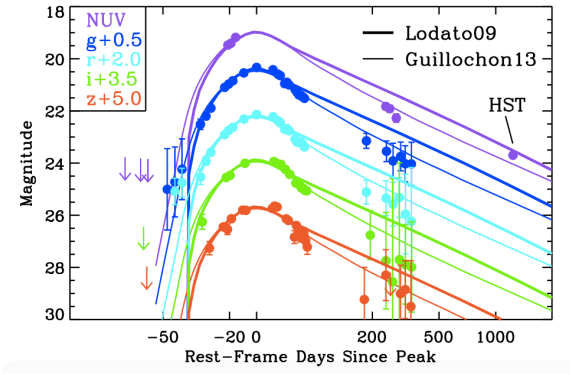


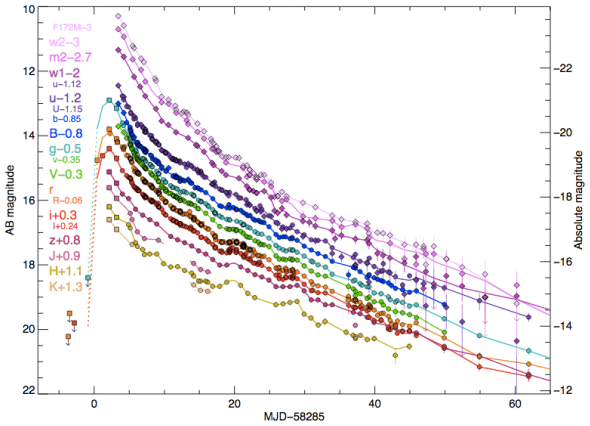


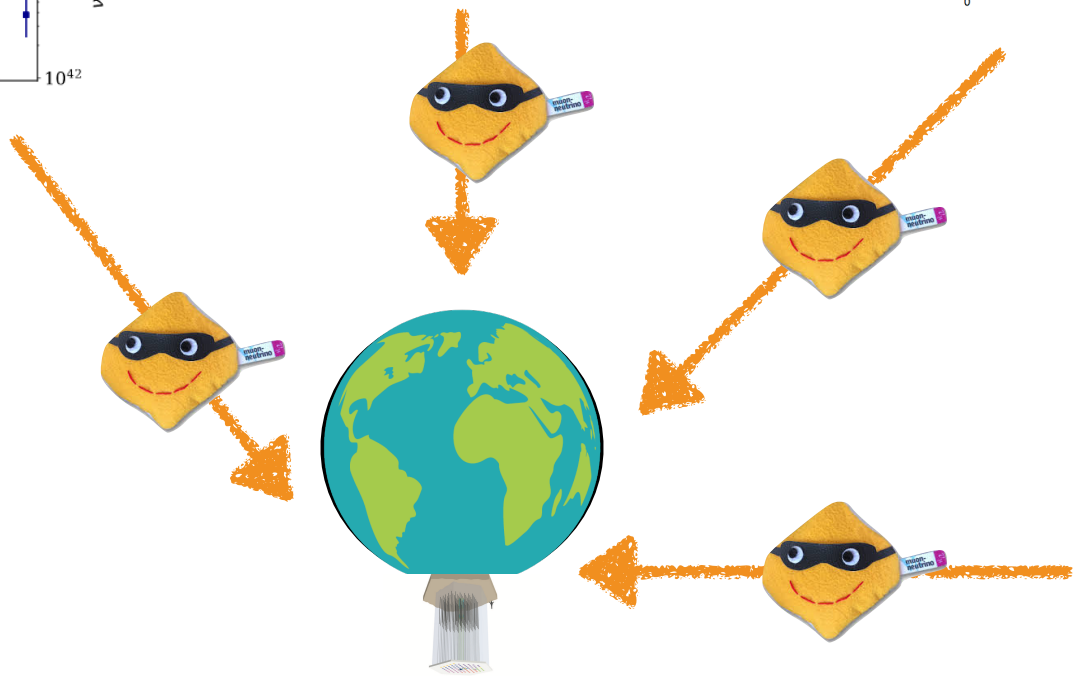
A&A **622**, L9 (2019)
Strotjohann et al.

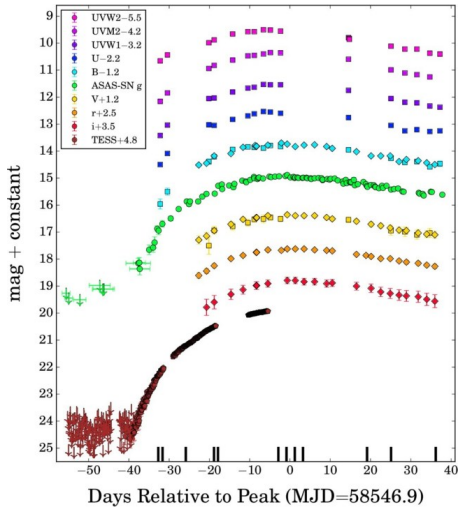
How special is AT2019dsg? An Eddington bias problem…











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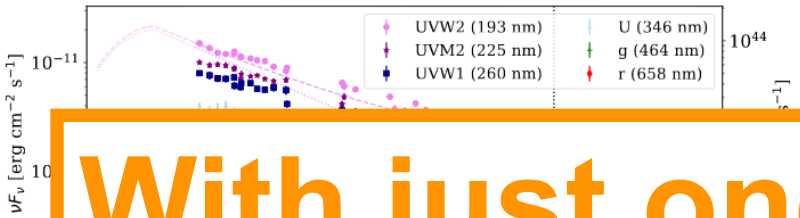
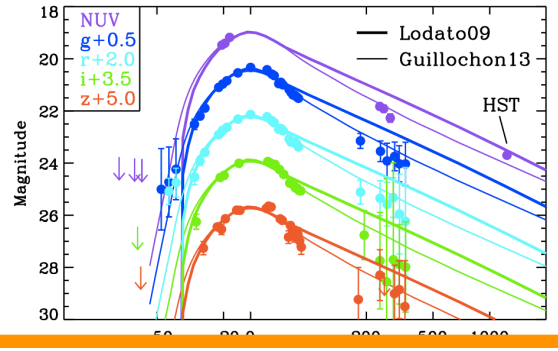
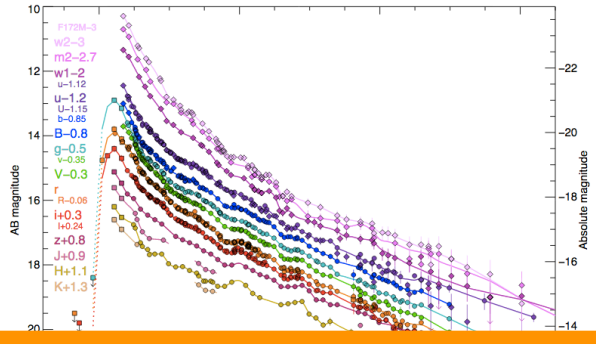
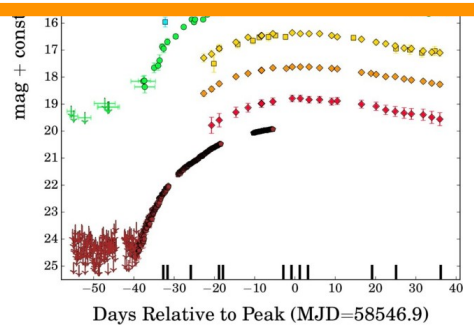
How special is AT2019dsg? An Eddington bias problem…







With just one event, exact neutrino flux distribution across TDEs is unknown. But AT2019dsg is probably not unique!



A&A **622**, L9 (2019)
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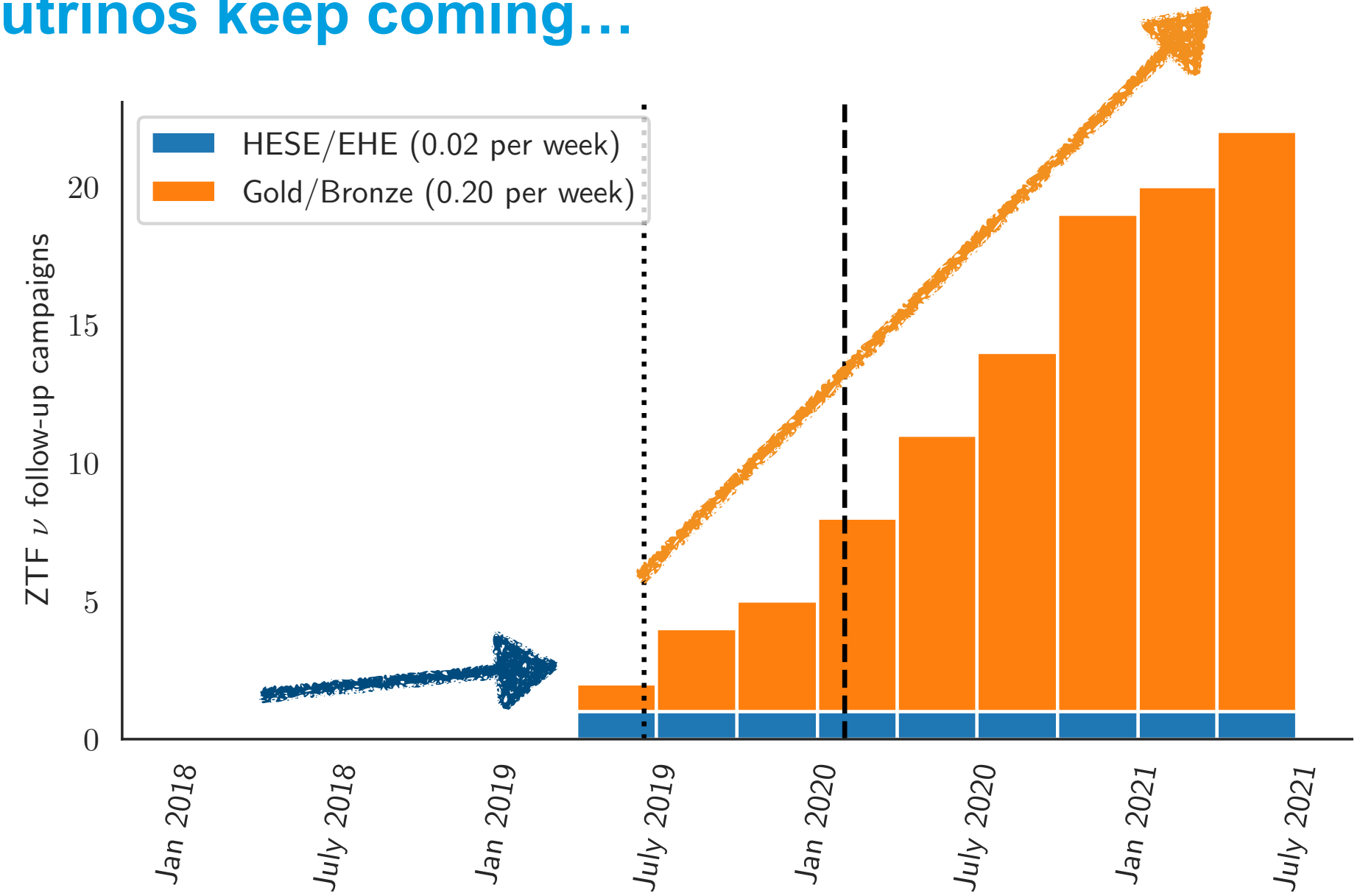
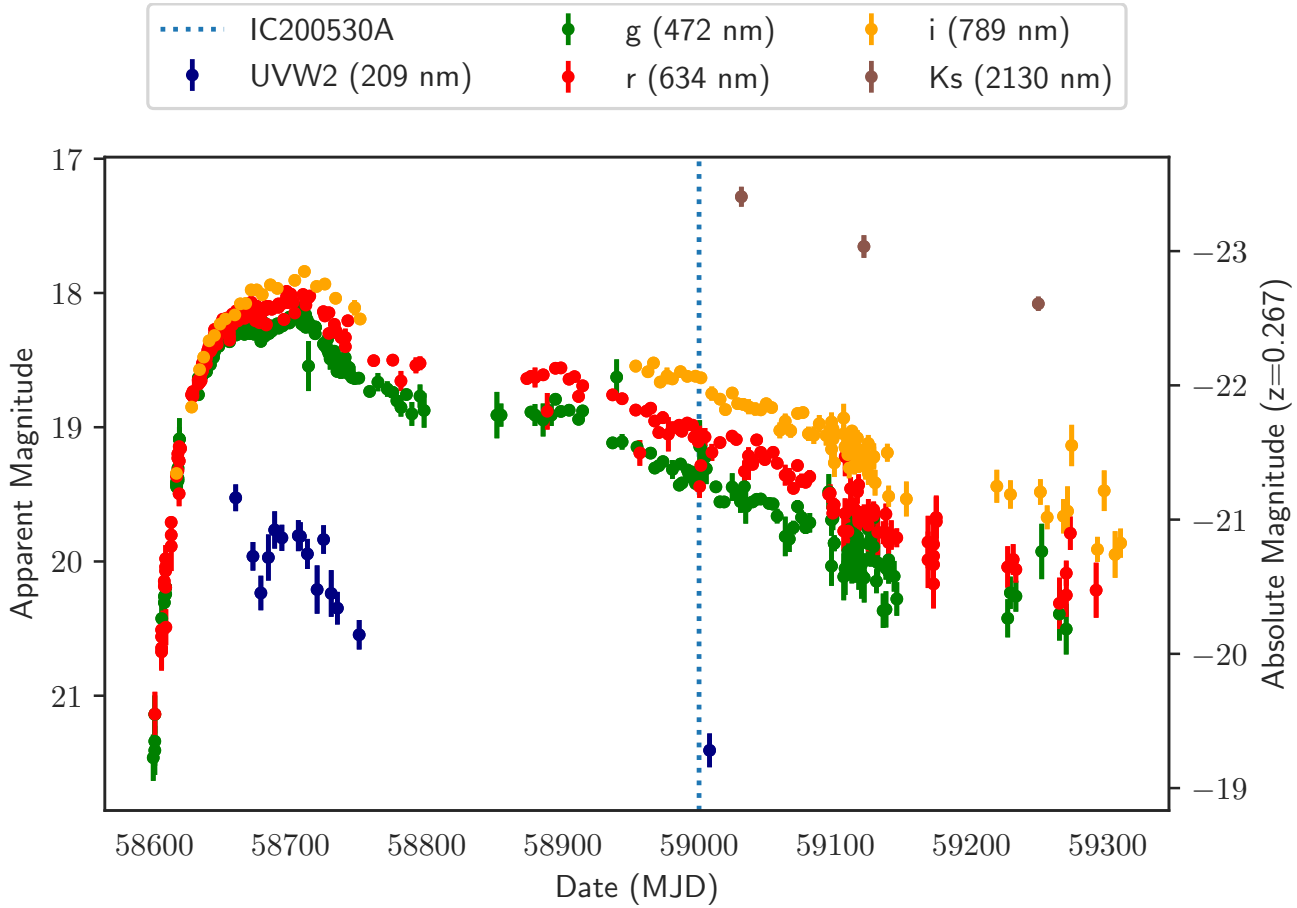
The search continues…

The neutrinos keep coming…



The search continues…



Have since found second event, AT2019fdr, coincident with IC200530A.

Second paper in prep, led by S. Reusch.

AT2019fdr: a probable TDE in a Narrow-Line Seyfert Galaxy

A Family Tree of Optical Transients from Narrow-Line Seyfert 1 Galaxies

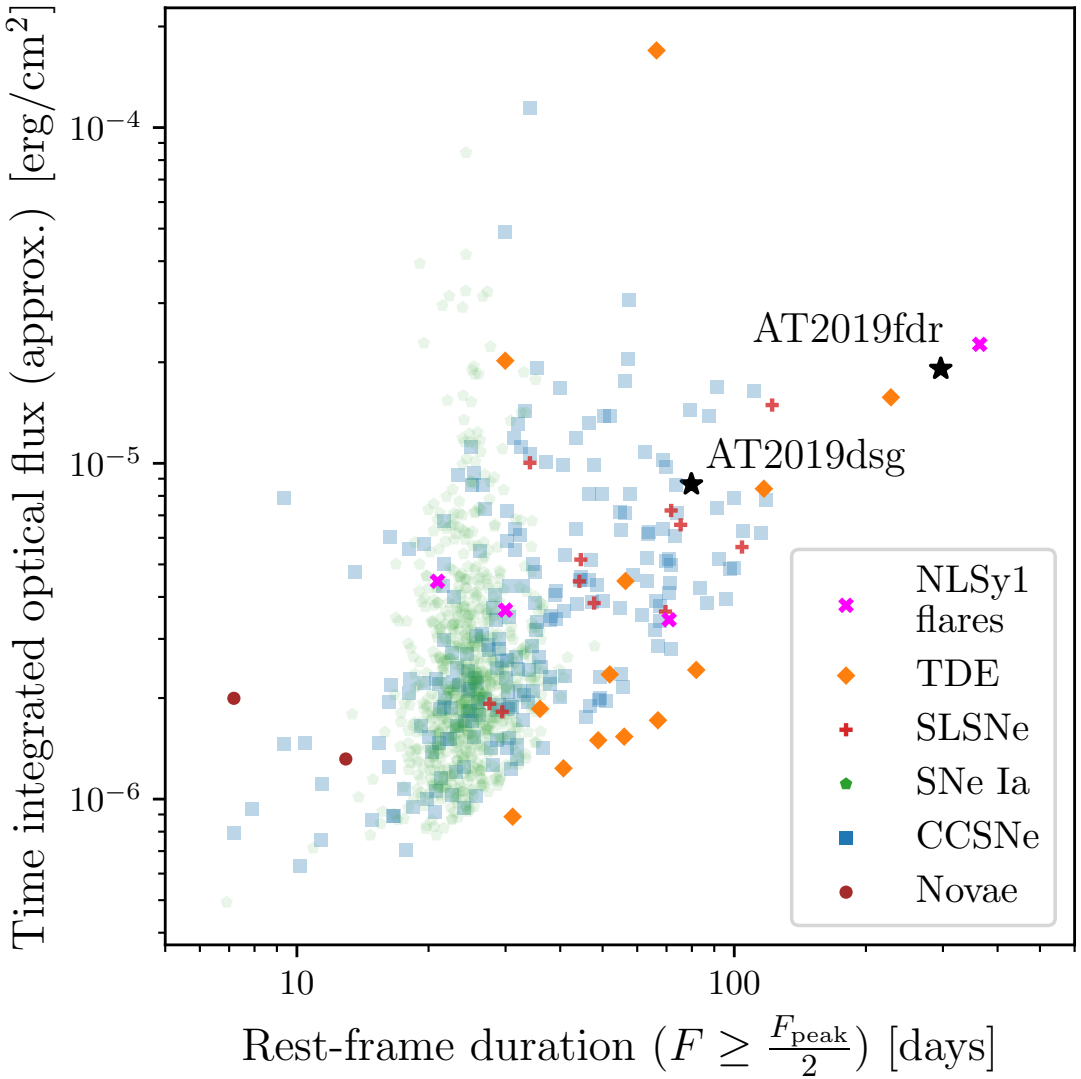
Sara Frederick [1], Suvi Gezari [1,2,3], Matthew J. Graham [4], Jesper Sollerman [5], Sjoert van Velzen [6], Daniel A. Perley [7], Daniel Stern [8], Charlotte Ward [1], Erica Hammerstein [1], Tiara Hung [9], Lin Yan [10], Igor Andreoni [11], Eric C. Bellm [12], Dmitry A. Duev [4], Marek Kowalski [13,14,15], Ashish A. Mahabal [11,16], Frank J. Masci [17], Michael Medford [18,19], Ben Rusholme [17], and Richard Walters [10]

Name	logM_{BH}<8 [$M_\odot$]	Hβ<2000 km s^{-1}	Fe II	[OIII]/Hβ < 3 [flux ratio]	$\Delta g - r$ ~ 0 mag	UV-bright	X-ray Γ	W1-W2 >0.7 mag[a]	Re-brighten	Spec. class	Interp.
ZTF19abvgxrq	✓	✓	×	✓	✓	✓	3	×	✓	HeII+NIII	AGN
ZTF19aailpwl	×	✓	✓	✓	✓	✓	✓[b]	✓	×	HeII+NIII	AGN
ZTF19aatubsj	✓	✓	✓	✓	×	✓	×	×	×	FeII	TDE
ZTF19aaiqmgl	✓	✓	✓	✓	×	✓	5	×	✓	HeII+NIII	AGN
ZTF18abjjkeo	✓	✓	×	✓	✓	-	-	×	×	HeII	TDE

AT2019fdr studied as part of a systematic study of extreme outbursts in classified NLSy1 Galaxies.

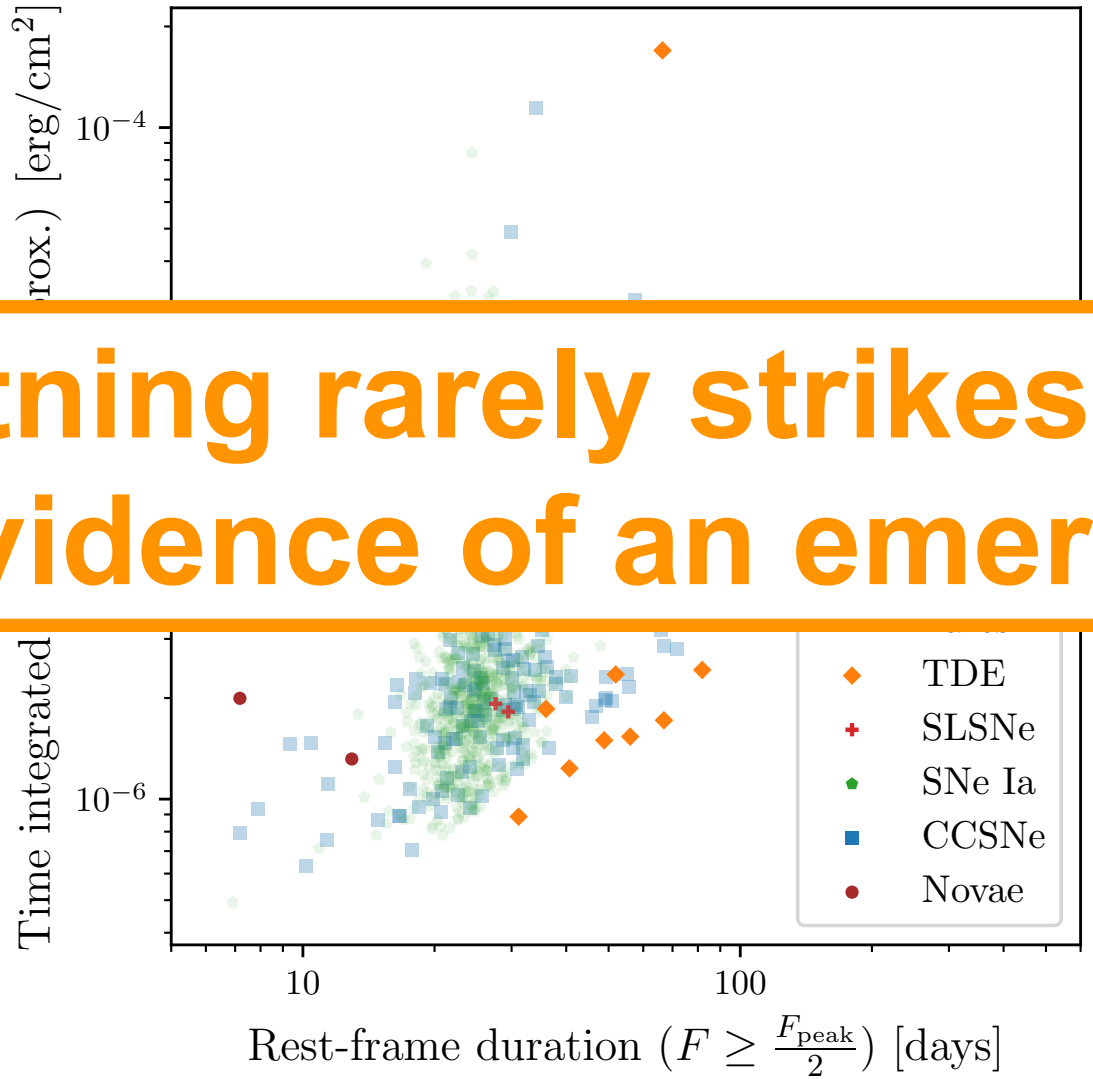
Classified as a probable TDE, but cannot exclude an AGN flare origin.

Neutrino-coincident transients are extremely energetic!



Credit: S. Reusch

Neutrino-coincident transients are extremely energetic!



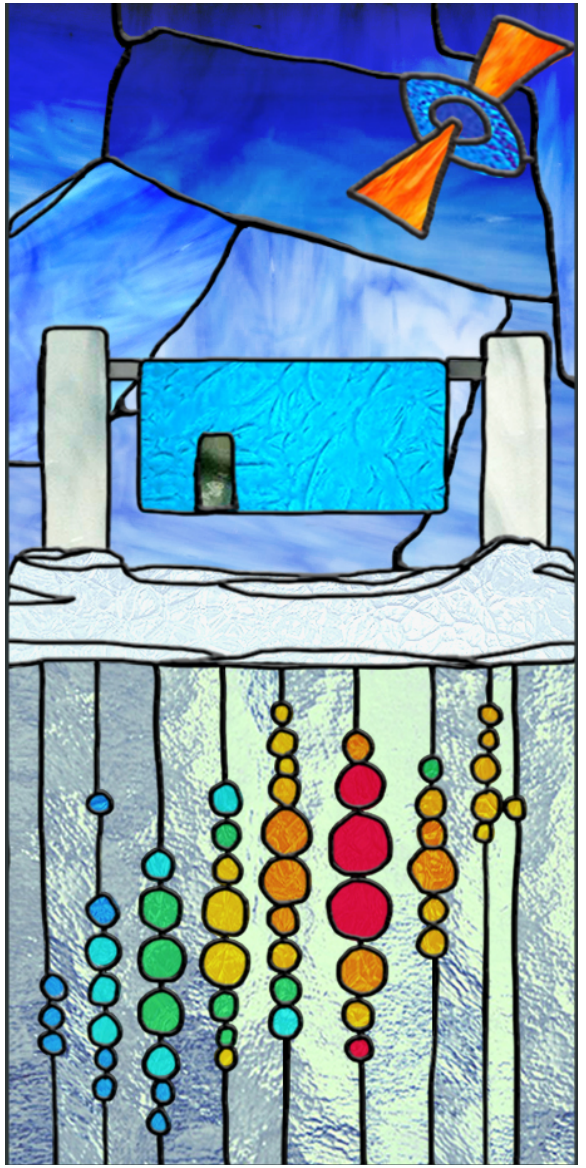
Lightning rarely strikes twice!
Strong evidence of an emerging trend.

Credit: S. Reusch

Summary

Summary

- Still searching for sources of astrophysical neutrinos
- ZTF has a dedicated neutrino follow-up program
- Bright TDE AT2019dsg found coincident with high-energy neutrino IC191001A. Conditions in this TDE appear consistent with production of ~0.2 PeV neutrino
- TDEs like AT2019dsg are being discovered in ever-increasing numbers.
- The search for neutrino counterparts continues. We hope AT2019dsg is the just the first of many associations. Already have a second probable neutrino TDE, AT2019fdr.



Credit: IceCube