Neutrinos from tidal disruption events

Robert Stein

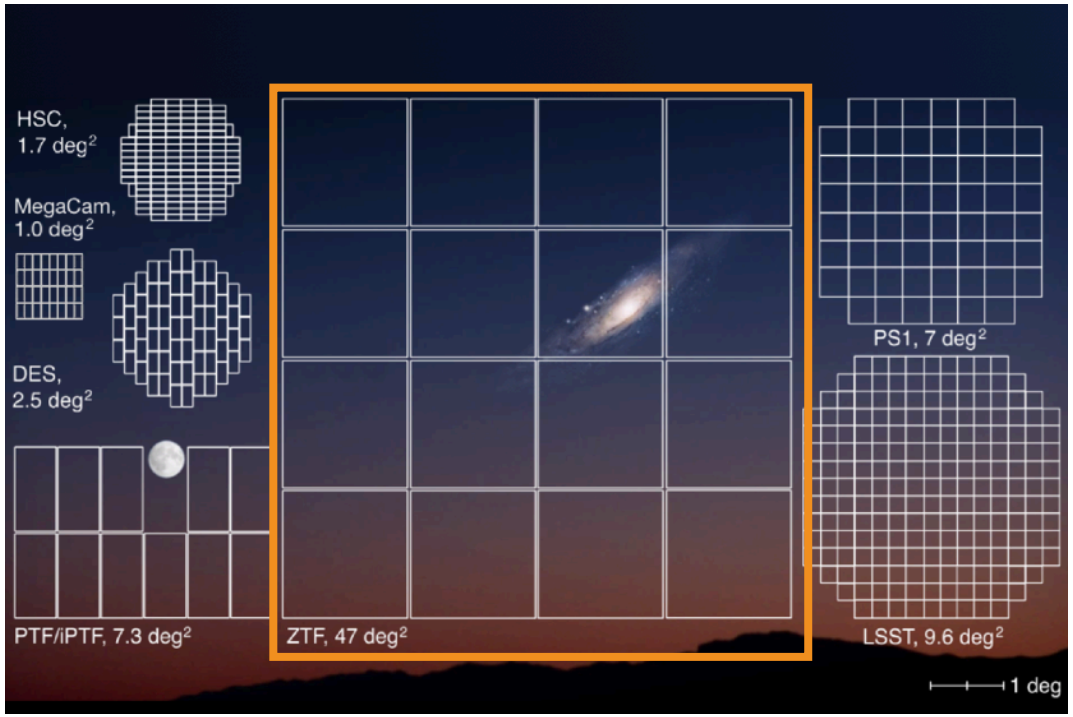
Cosmic Rays and Neutrinos in the Multi-Messenger Era, 11/12/20

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

DESY.

The Zwicky Transient Facility (ZTF)



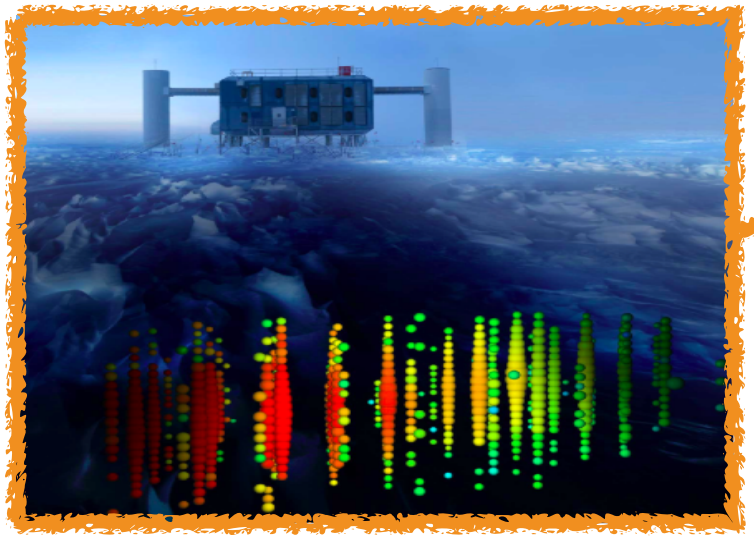
ZTF is an optical telescope with huge 47 sq. deg f.o.v. Optimised for volumetric survey speed.

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

Designed as a stepping stone from “scrapbook astronomy” to “big data astronomy”

The neutrino follow-up program

~500k objects per night

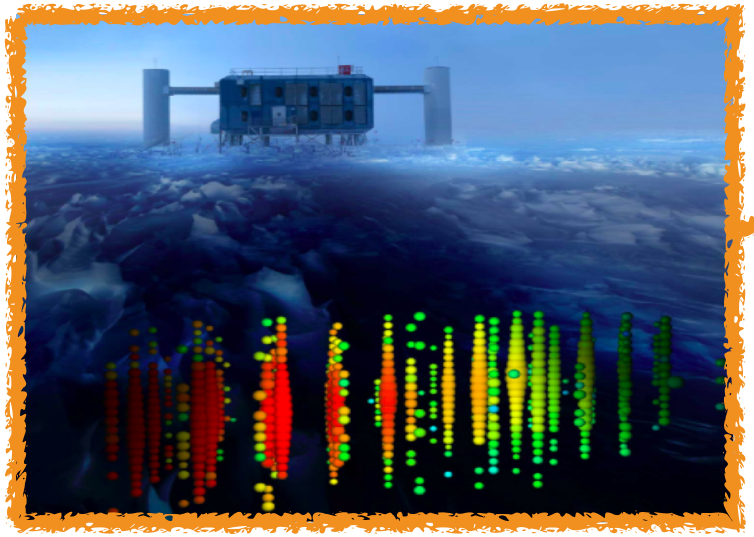


Neutrino direction and time

Find counterpart?

The neutrino follow-up program

~500k objects per night



Neutrino direction and time

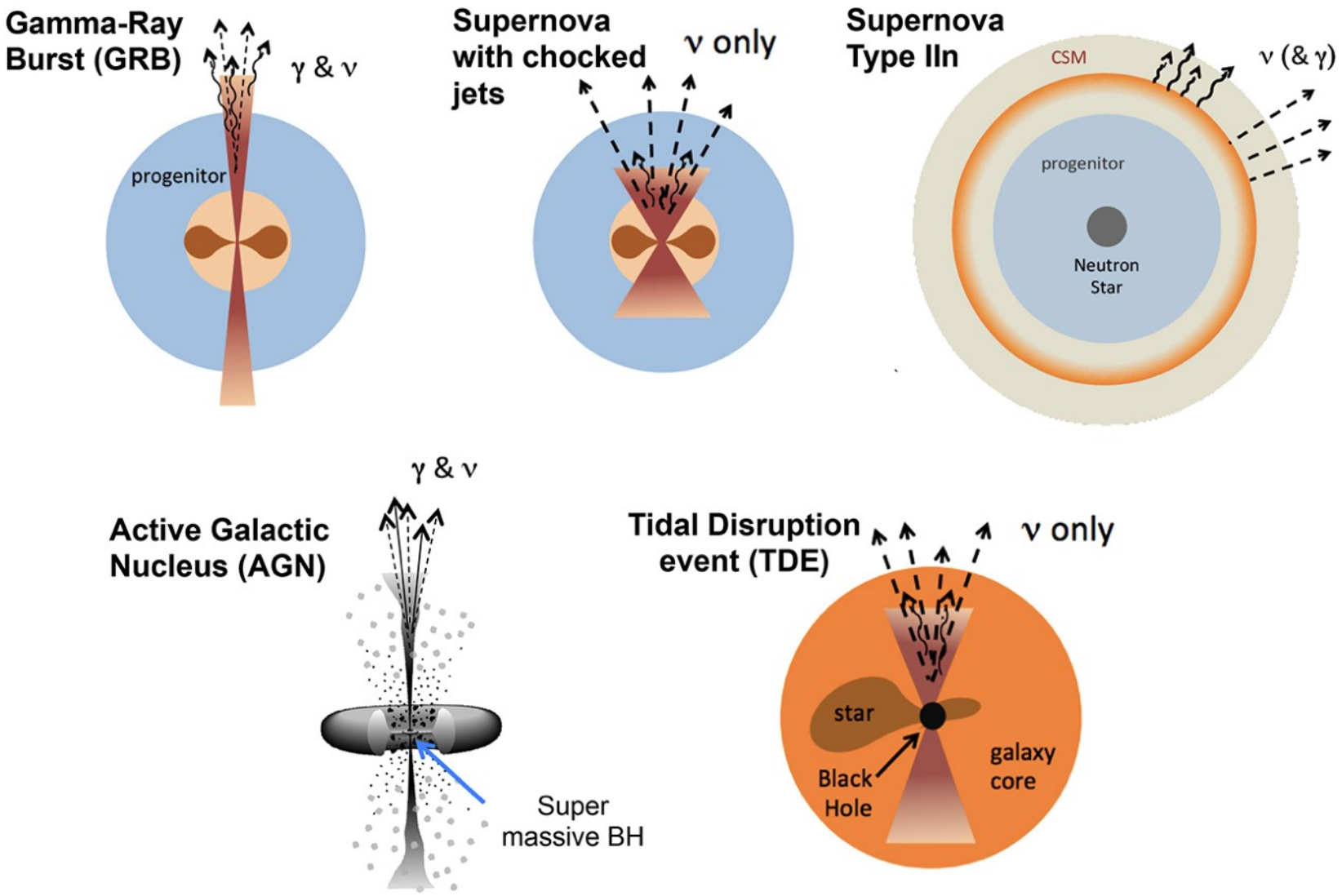
Reject stars, asteroids, planets

Correlate

Spectroscopically classify few remaining objects

Find counterpart?

What are we looking for?



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.

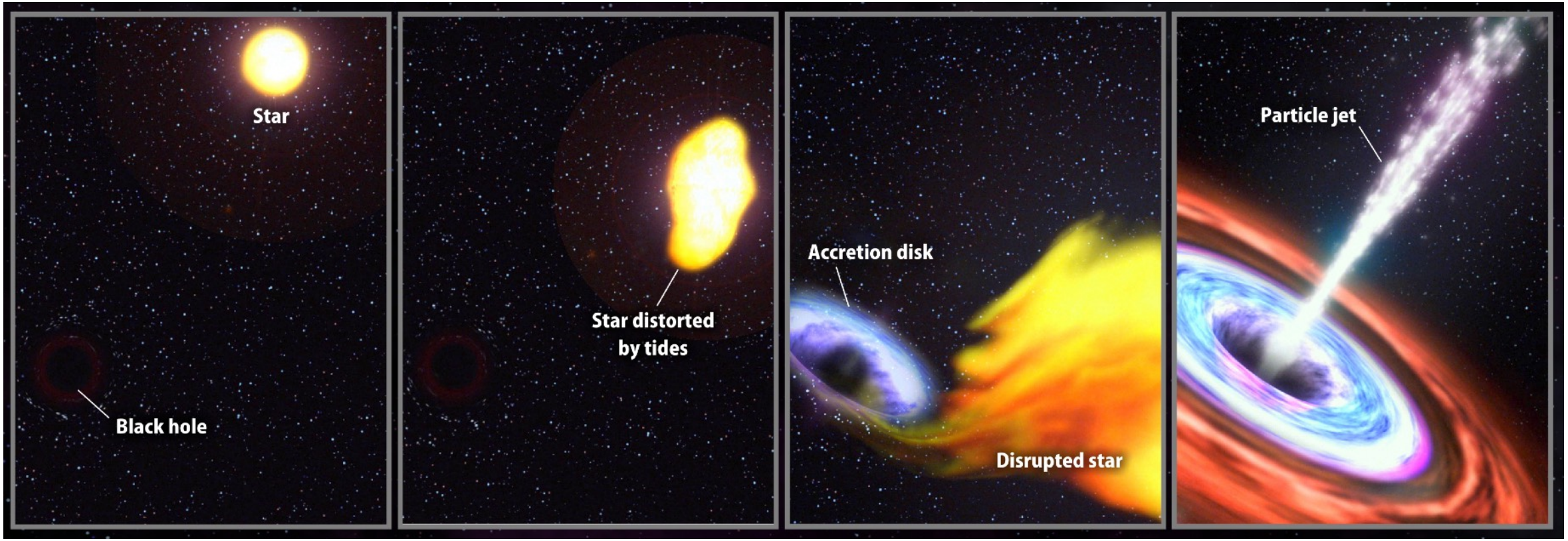
23/31 alerts not followed-up

Cause	Events
Alert Retraction	*IC180423A*[56], *IC181031A*[57], *IC190205A*[58], *IC190529A*[59]
Proximity to Sun	*IC180908A*[60], *IC181014A*[61], *IC190124A*[62], *IC190704A*[63]
	IC190712A[64], *IC190819A*[65], *IC191119A*[66], *IC200227A*[67]
Low Altitude	*IC191215A*[68]
Southern Sky	*IC190331A*[69], *IC190504A*[70]
Poor Signalness & Localisation	*IC190221A*[71], *IC190629A*[72], *IC190922A*[73]
	IC191122A[74], *IC191204A*[75], *IC191231A*[76]
Bad Weather	*IC200120A*[77,78]
Telescope Maintenance	*IC181023A*[79]

Table 2: Summary of the 23 neutrino alerts that were not followed up by ZTF since survey start on 2018 March 20. Of these, 4/23 were retracted, 11/23 were inaccessible to ZTF for various reasons, 6/23 were deemed alerts of poor quality, while just 2/23 were due to telescope downtime.

ZTF has (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.

What are Tidal Disruption Events (TDEs)?

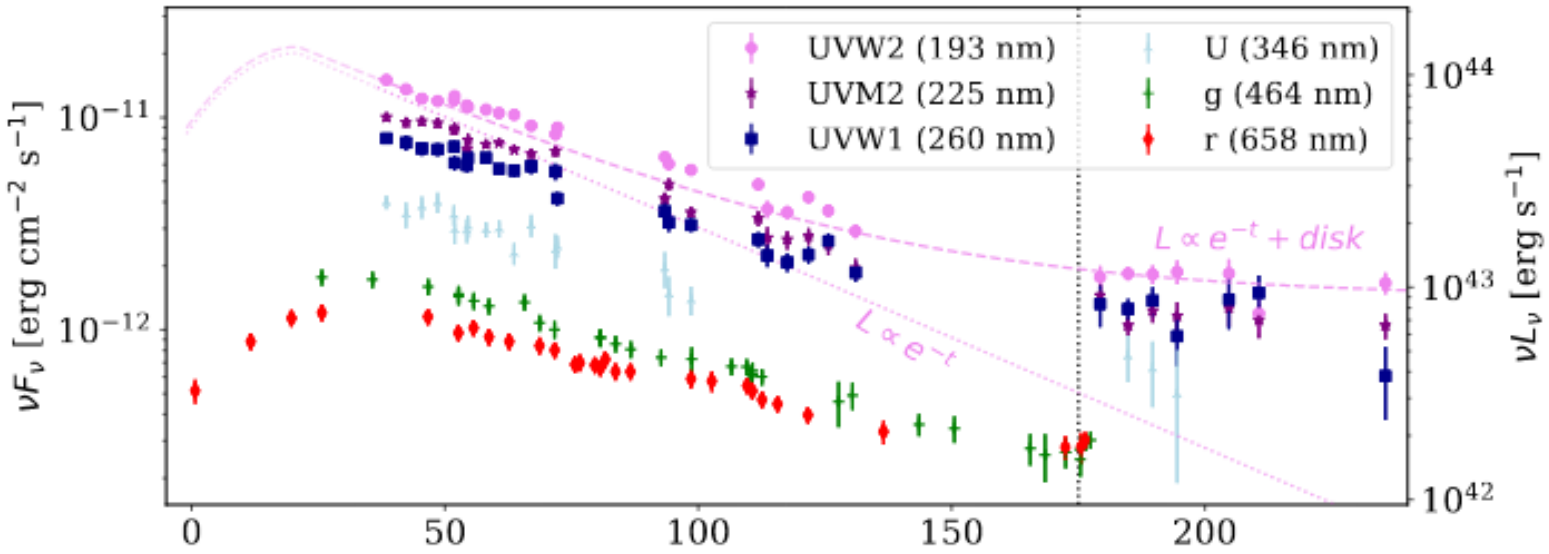


Credit: NASA

1 2 3 4

IC191001A + AT2019dsg

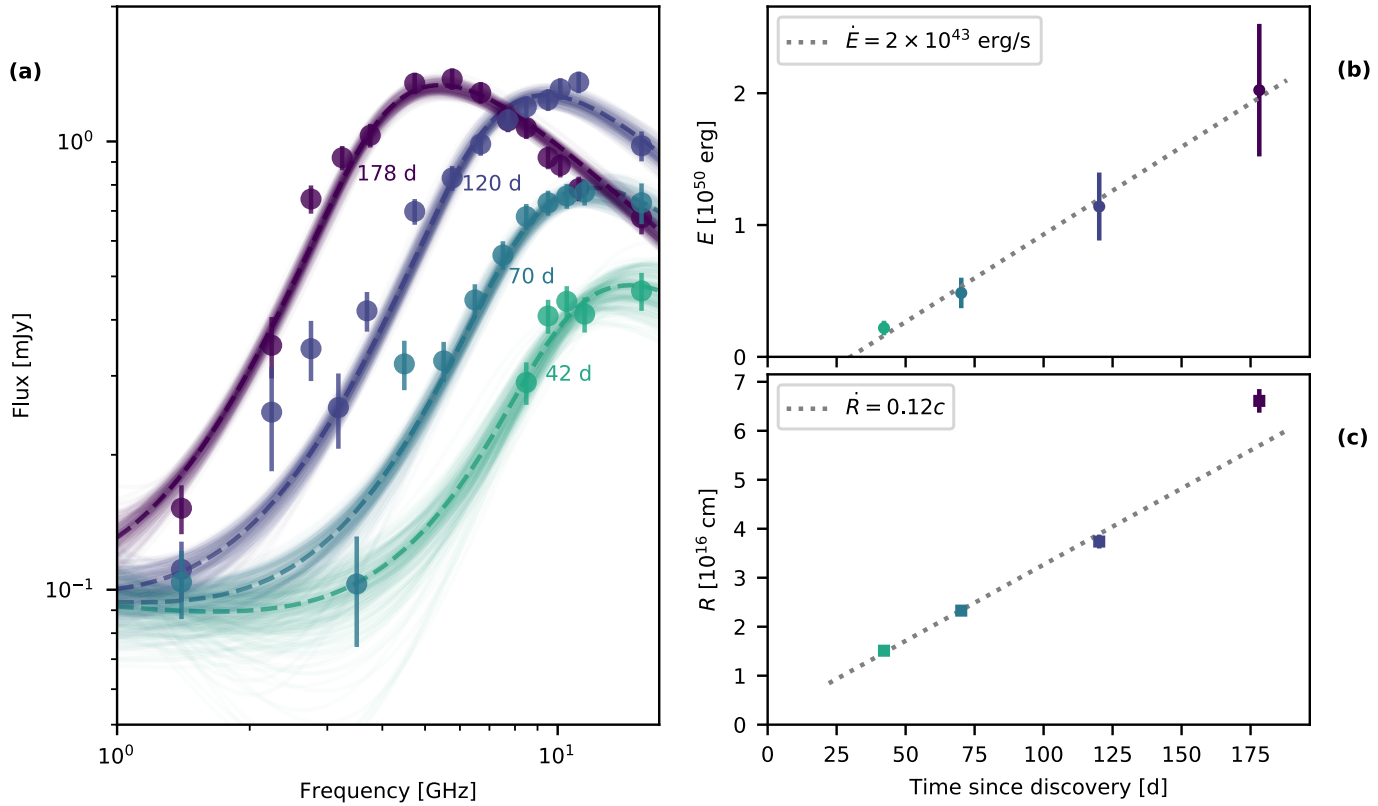
https://arxiv.org/abs/2005.05340



Bright, radio-emitting TDE found coincident with IC191001A.

TDEs are rare. Accounting for all 8 neutrino campaigns and ZTF RE TDE density (1 per 10000 sq. deg.), the probability to find any coincident radio-emitting TDE is 0.5%.

Radio data is unprecedented for a TDE



Radio analysis reveals extended synchrotron-emitting outflow. ~Linearly increasing energy to ~2 x10^{50} ergs.

Reveals a central engine! (First direct evidence). Active through to time of neutrino detection.

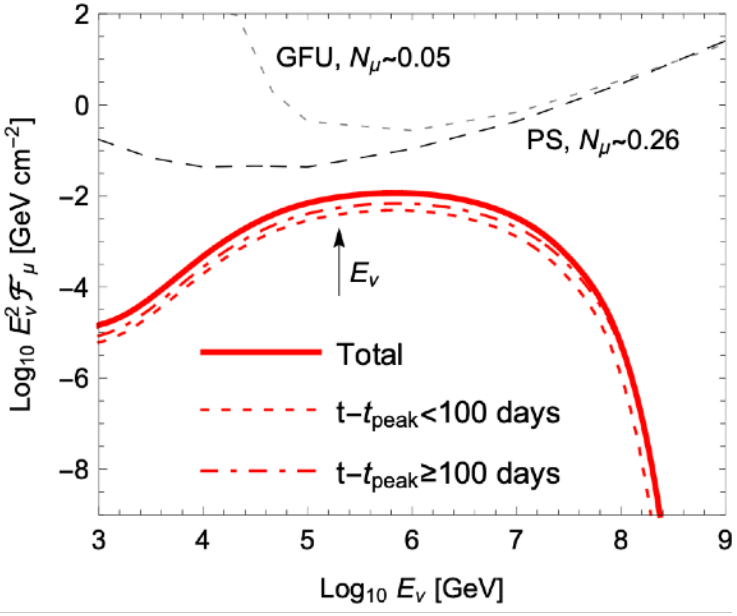
Multi-wavelength data shows conditions compatible with neutrino production.

Suggests TDEs contribute to the astrophysical neutrino flux (>3% of total).

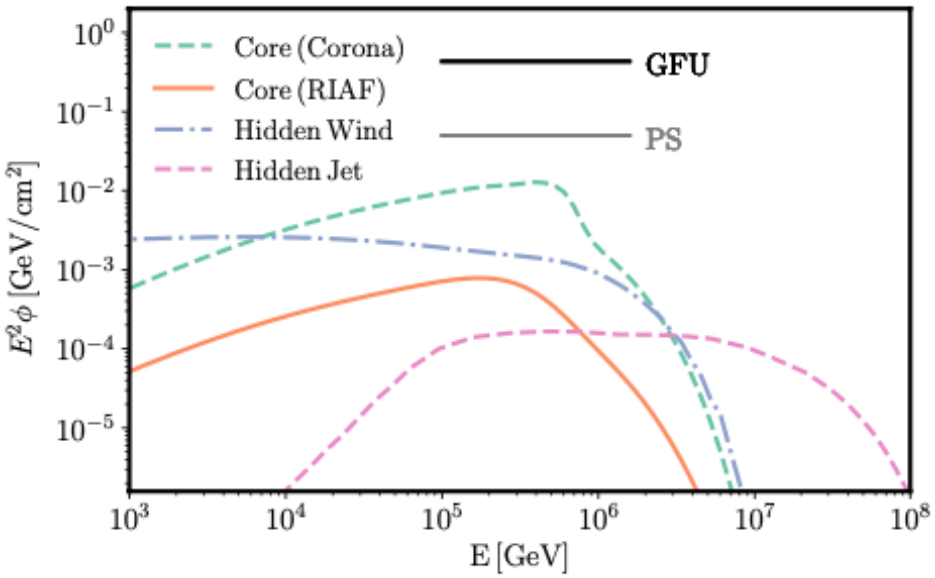
Modelling Neutrino Production in AT2019dsg

https://arxiv.org/abs/2005.06097 http://arxiv.org/abs/2005.08937 https://arxiv.org/abs/2011.03773

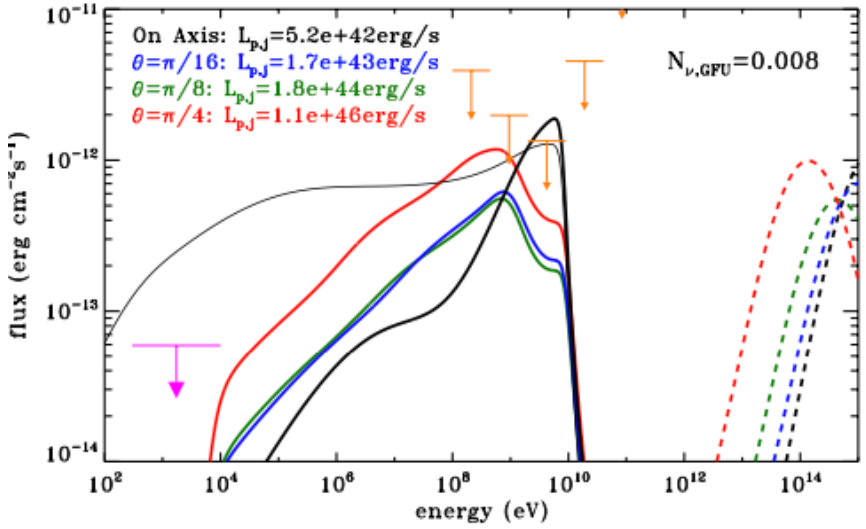
Winter & Lunardini



Murase, Kimura, Zhang, Oikonomou & Petropoulou

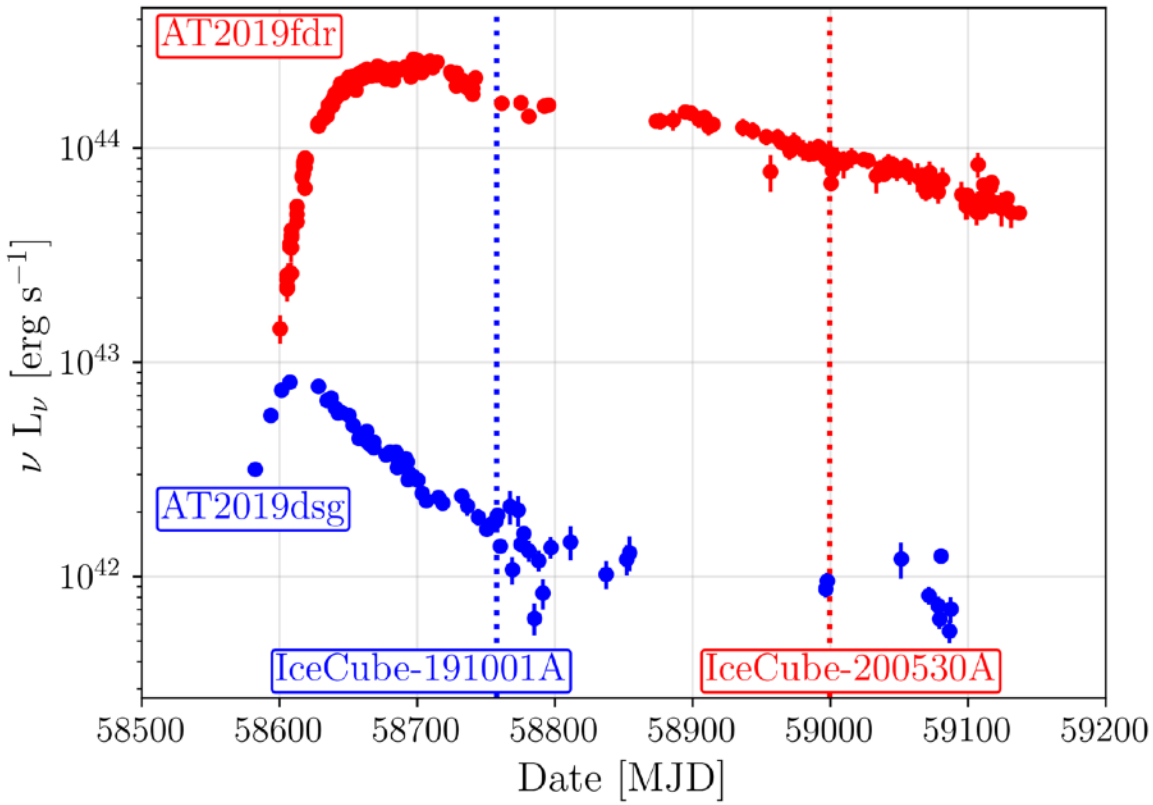


Liu, Xi & Wang



Like the case of TXS 0506+056, it is also important to account for the substantial Eddington Bias (https://arxiv.org/abs/1809.06865)

The search continues…



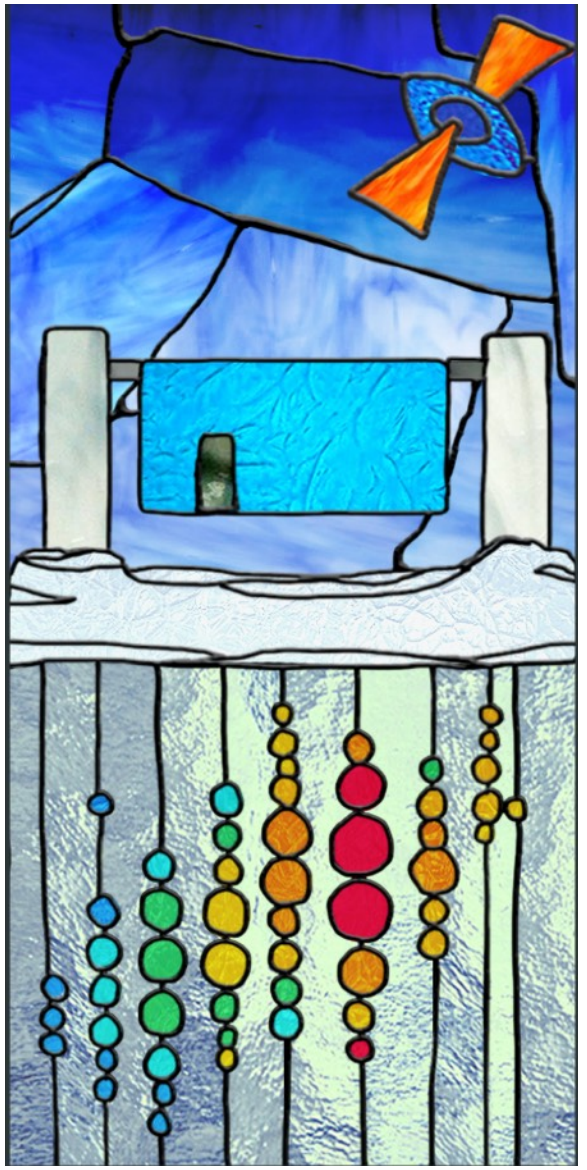
ZTF has now completed 18 follow-up campaigns to date, out of 57 neutrino alerts from IceCube.

Have since found second TDE, AT2019fdr, coincident with IC200530A. See Simeon Reusch's poster!

Lightning rarely strikes twice. Strong evidence of an emerging trend. Second paper in prep.

Summary

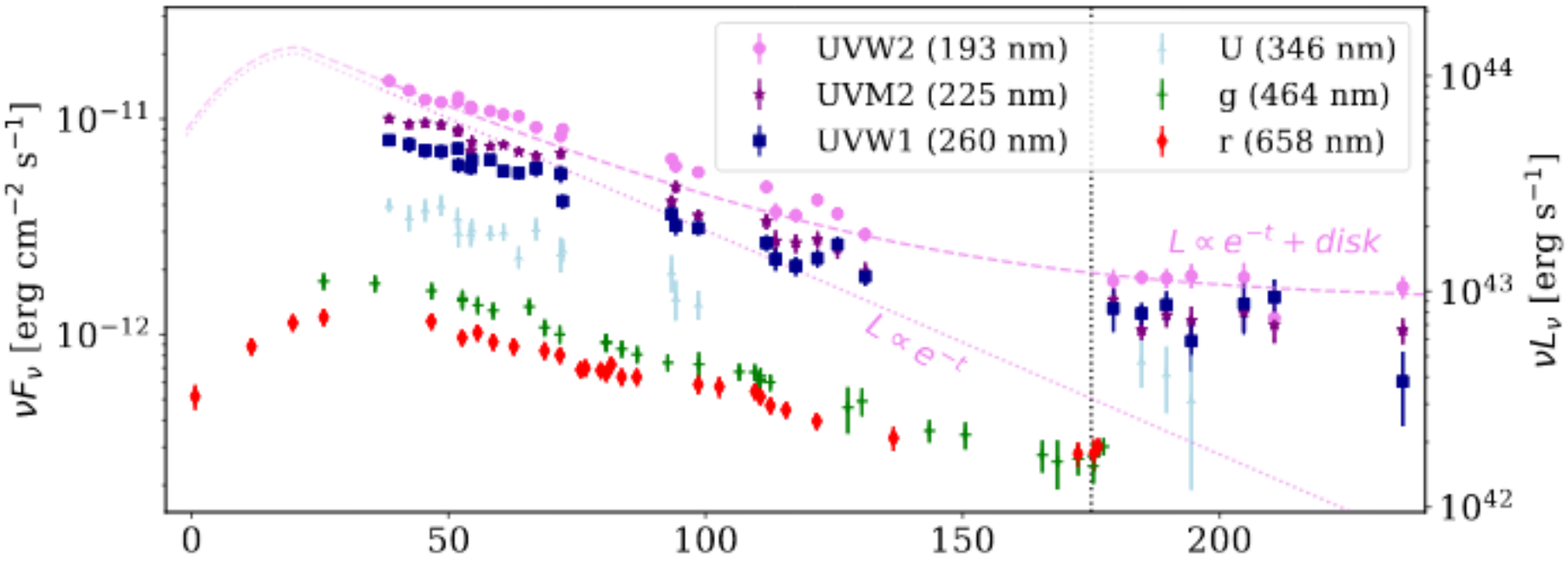
- ZTF has a dedicated neutrino follow-up program. Identified AT2019dsg as probable source of IC191001A.
- **Suggests TDEs contribute to the neutrino flux (>~3%), but doesn't require them to be the dominant population.**
- AT2019dsg paper should be published shortly.
- Have since found a second likely neutrino TDE, AT2019fdr, with paper in prep. See Simeon Reusch's poster for more info. **Strong evidence of an emerging trend.**
- **With ZTF, we are performing the first systematic search that can identify TDEs with high efficiency. Our program is continuing with ZTF-II, and we hope to find even more associations!**



Credit: IceCube

Backup

Introducing AT2019dsg ("ZTF-BranStark")



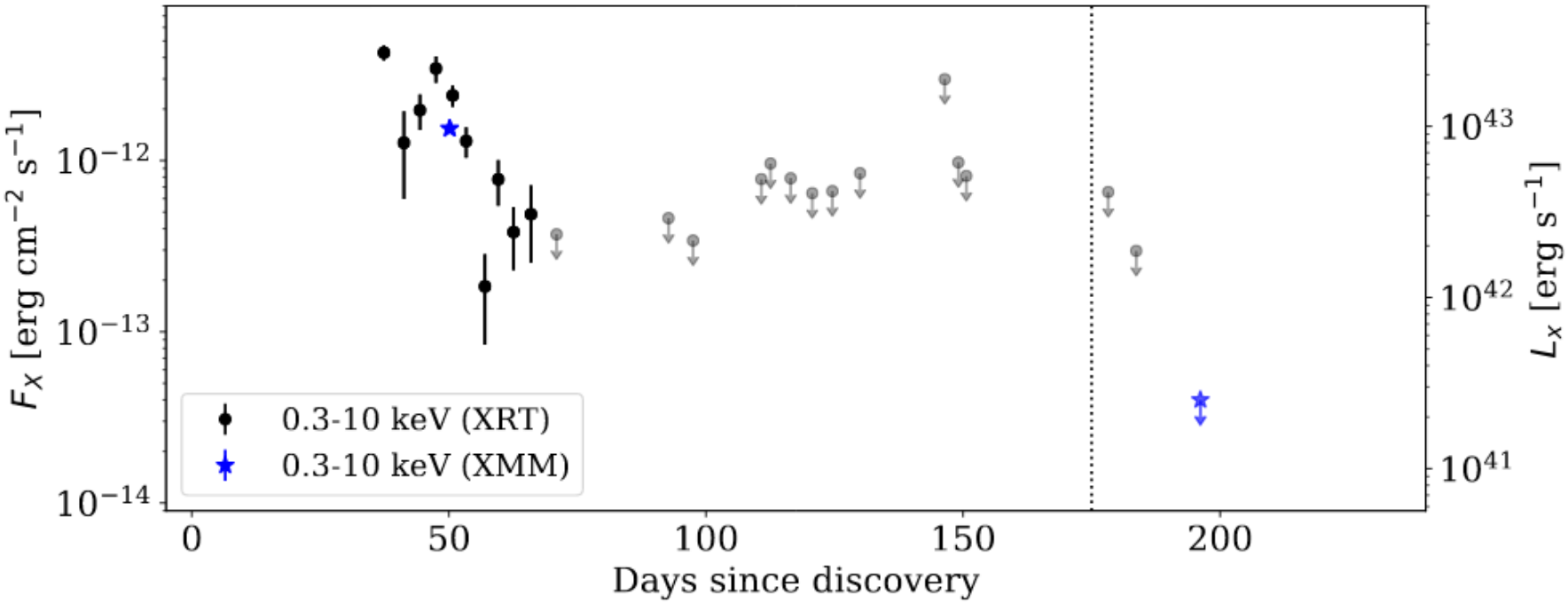
Discovered in April 2019 by ZTF, lots of data! Neutrino arrived ~175 days post-discovery.

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})

Relatively early/bright plateau, consistent with accretion disk formation. (z = 0.051)

Emission from pretty hot + bright UV photosphere

X-rays are more puzzling…



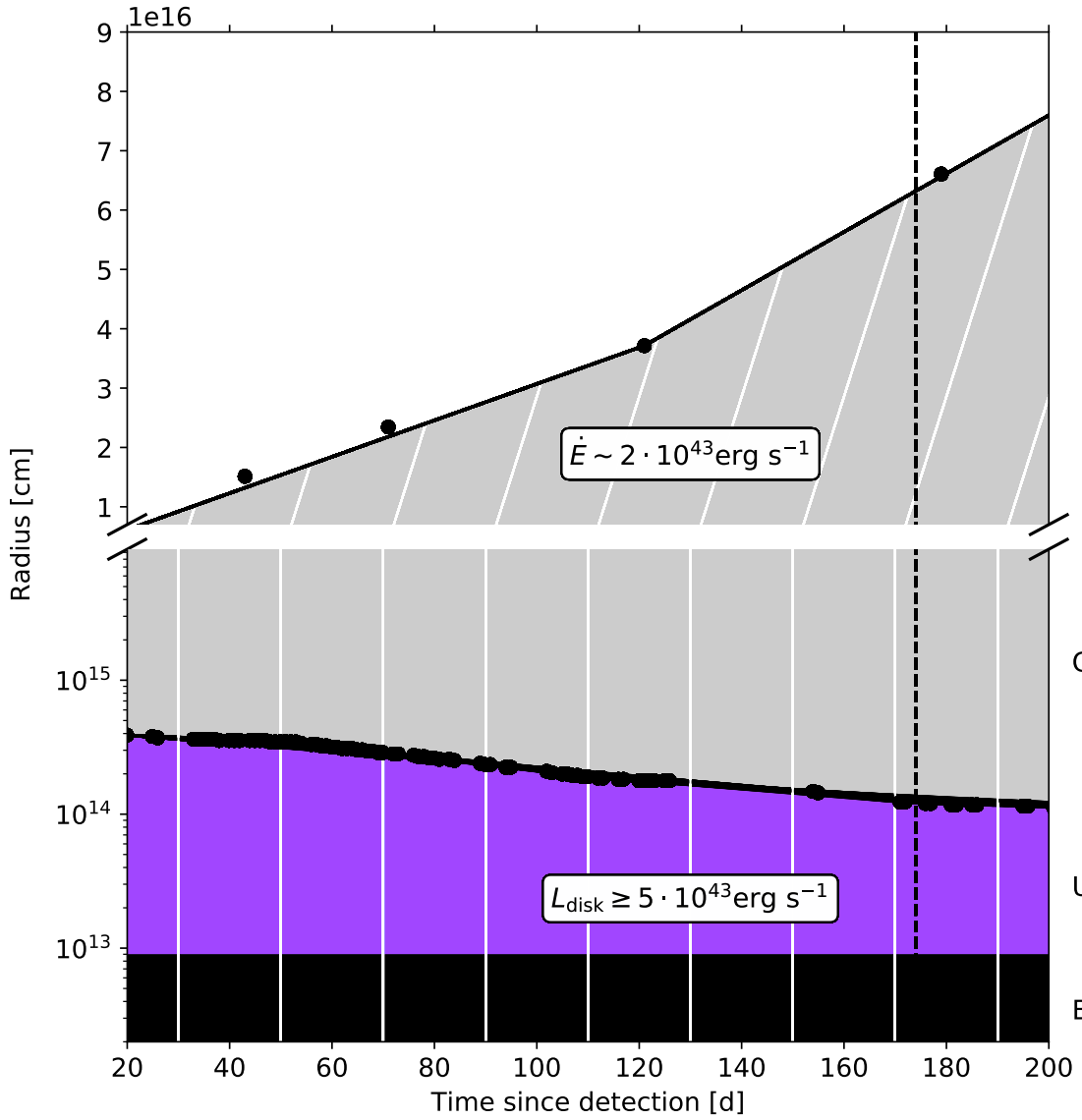
First observed around optical peak. Initially bright ($L_x/L_{opt} \sim 0.1$)

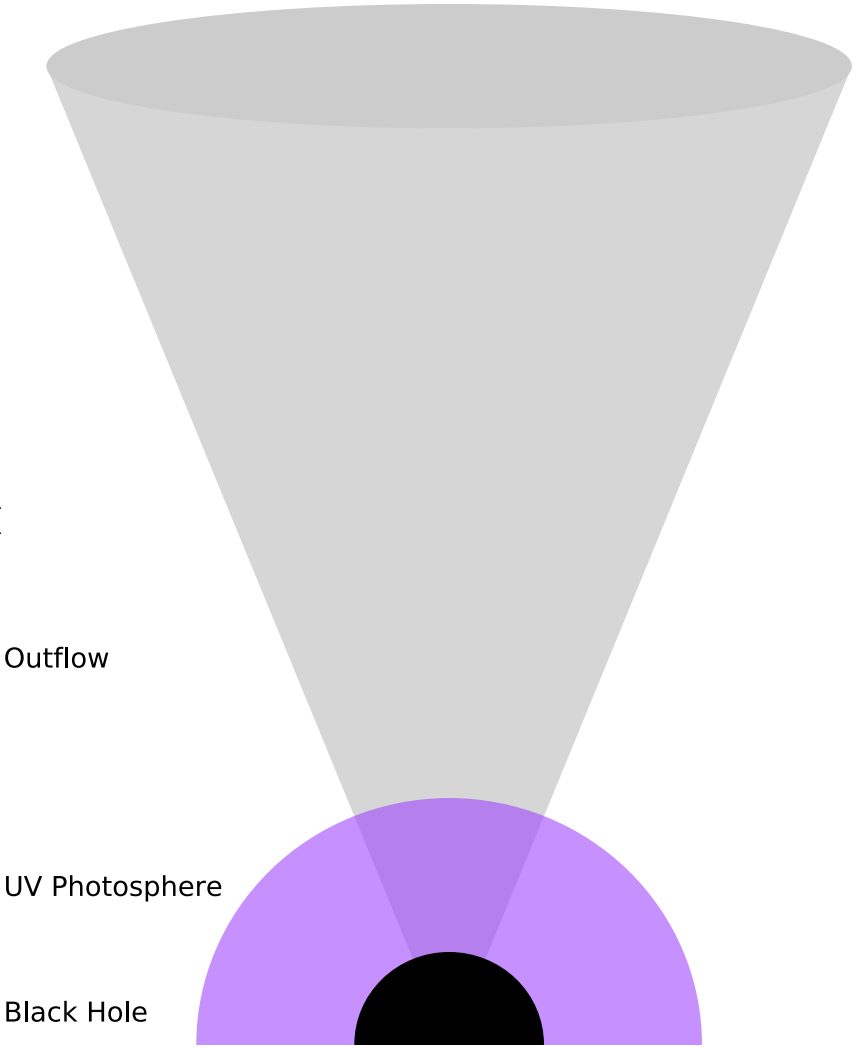
Fades extremely quickly. At least factor 100 decrease over ~170 days

As for other TDEs, described by thermal X-rays with $T \sim 10^{5.8}$ K, small inferred $R \sim 2 \times 10^{11}$ cm

X-rays from inner region. Fading due to cooling or obscuration? X-rays in TDEs are poorly-understood.

A combined multi-wavelength picture





AT2019dsg as a neutrino source

Less guessing, more data!

- Particle accelerator for protons? ✓ → Central engine revealed, with high inferred B fields to contain particles during acceleration, satisfies Hillas criteria
- Target for protons to collide with ✓ → Dense UV photosphere; Perhaps X-ray photosphere?; Ambient matter? (We do infer a high density)
- Sufficient system energy ✓ → Estimate $>10^{50}$ erg just from outflow. Consistent with expectations, given strong Eddington bias. (https://arxiv.org/abs/1809.06865)

Conditions consistent with requirements for ~PeV neutrino production