Image credit: DESY / Science Communication Lab

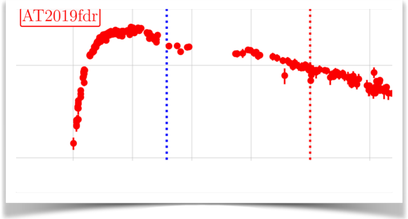
Multi-Messenger Emission of TDEs

ECRS / 28 July, 2022 / Simeon Reusch

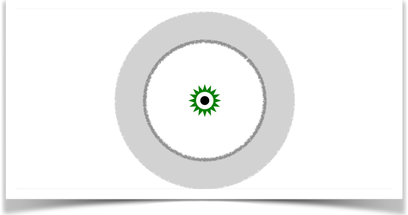
Overview

Motivation, Follow-Up Program

What are Tidal Disruption Events?



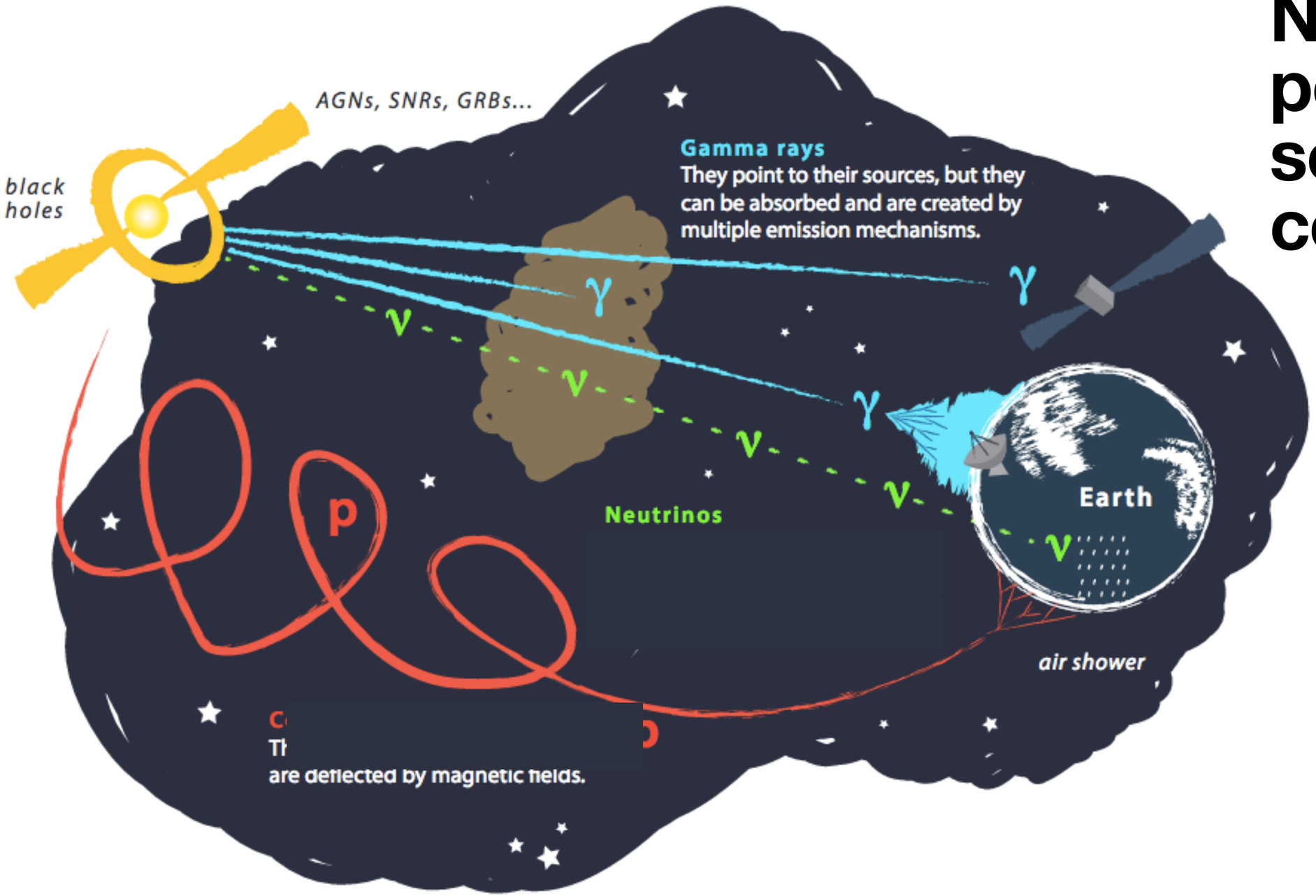
AT2019dsg and AT2019fdr



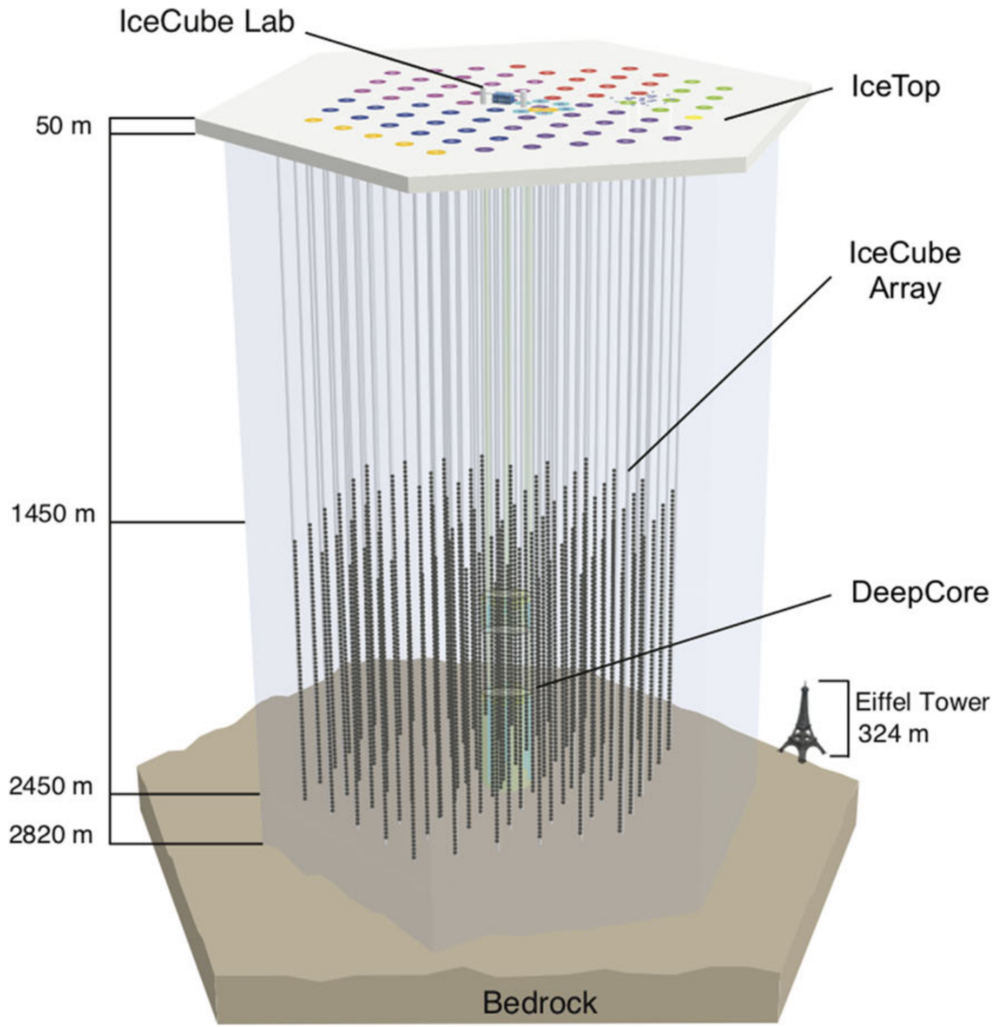
Dust Echoes + AT2019aalc

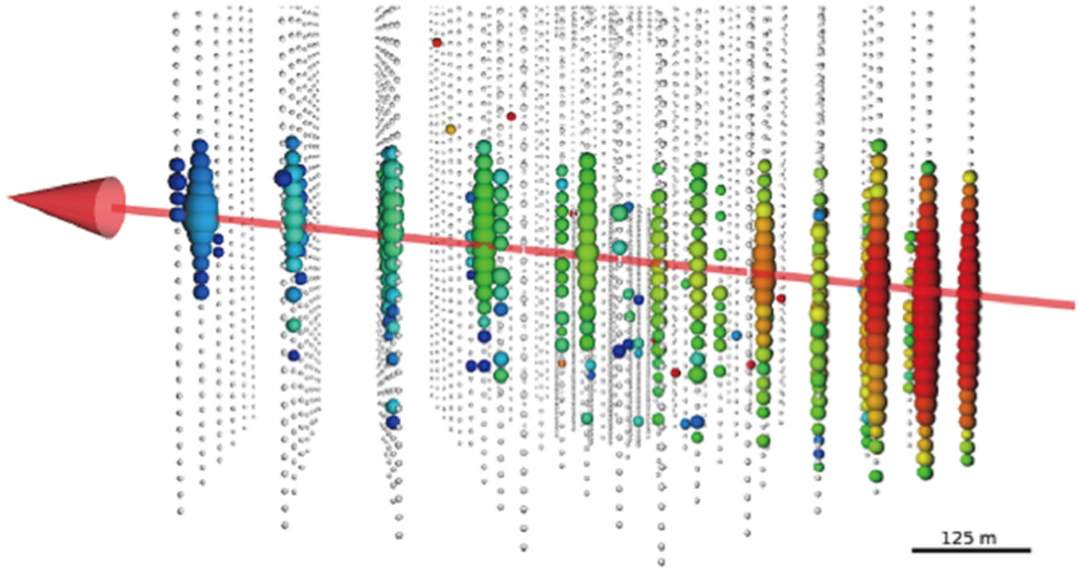
Outlook

Neutrinos point back the sources of cosmic rays!



Detecting neutrinos is HARD

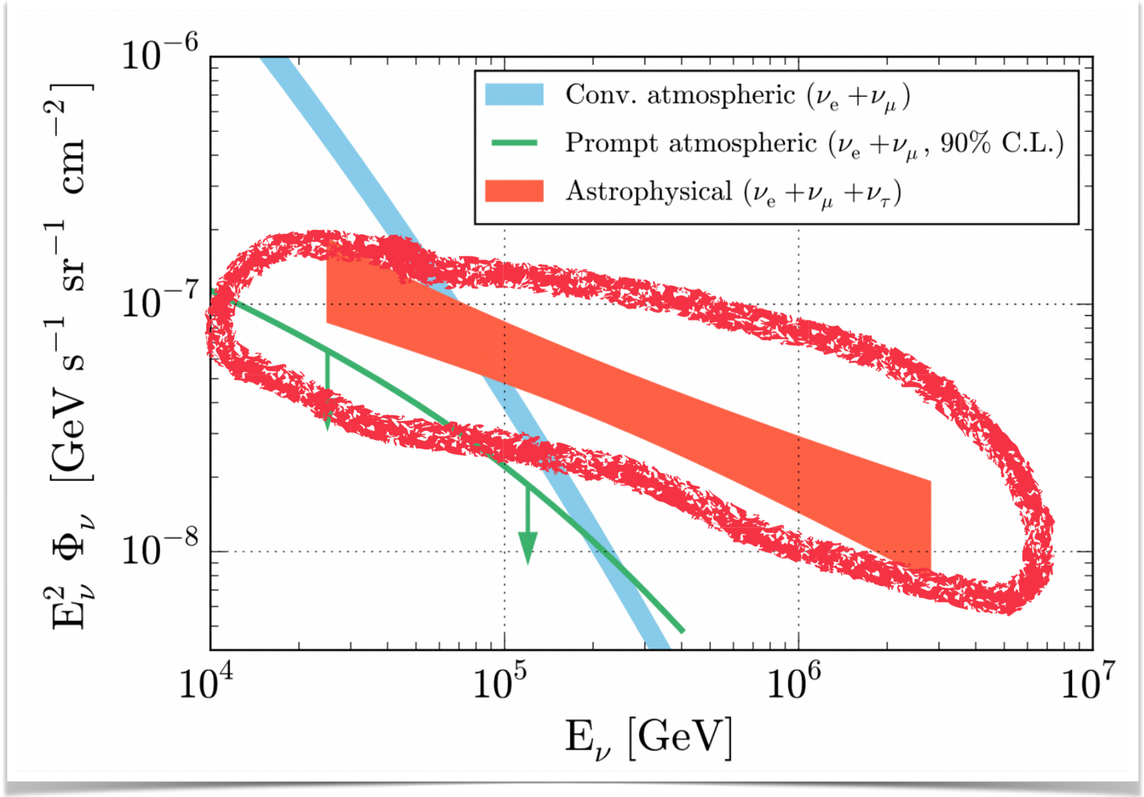


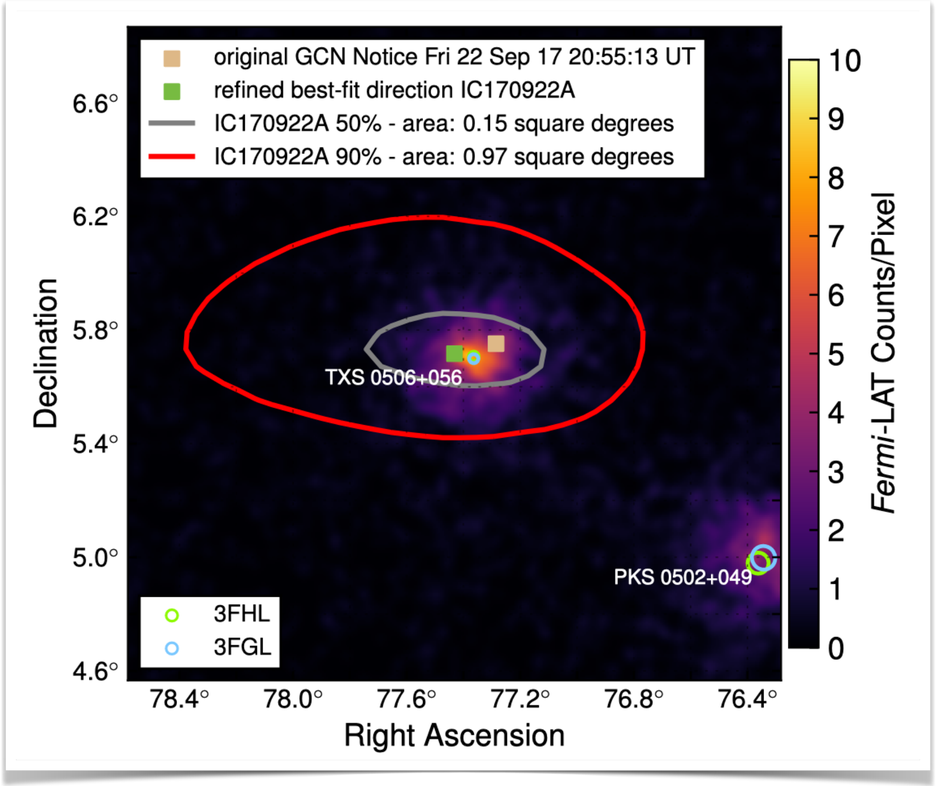


Event view of IceCube-170922

Identifying their sources too!

Cosmic high-energy neutrino flux first detected by IceCube (2013)



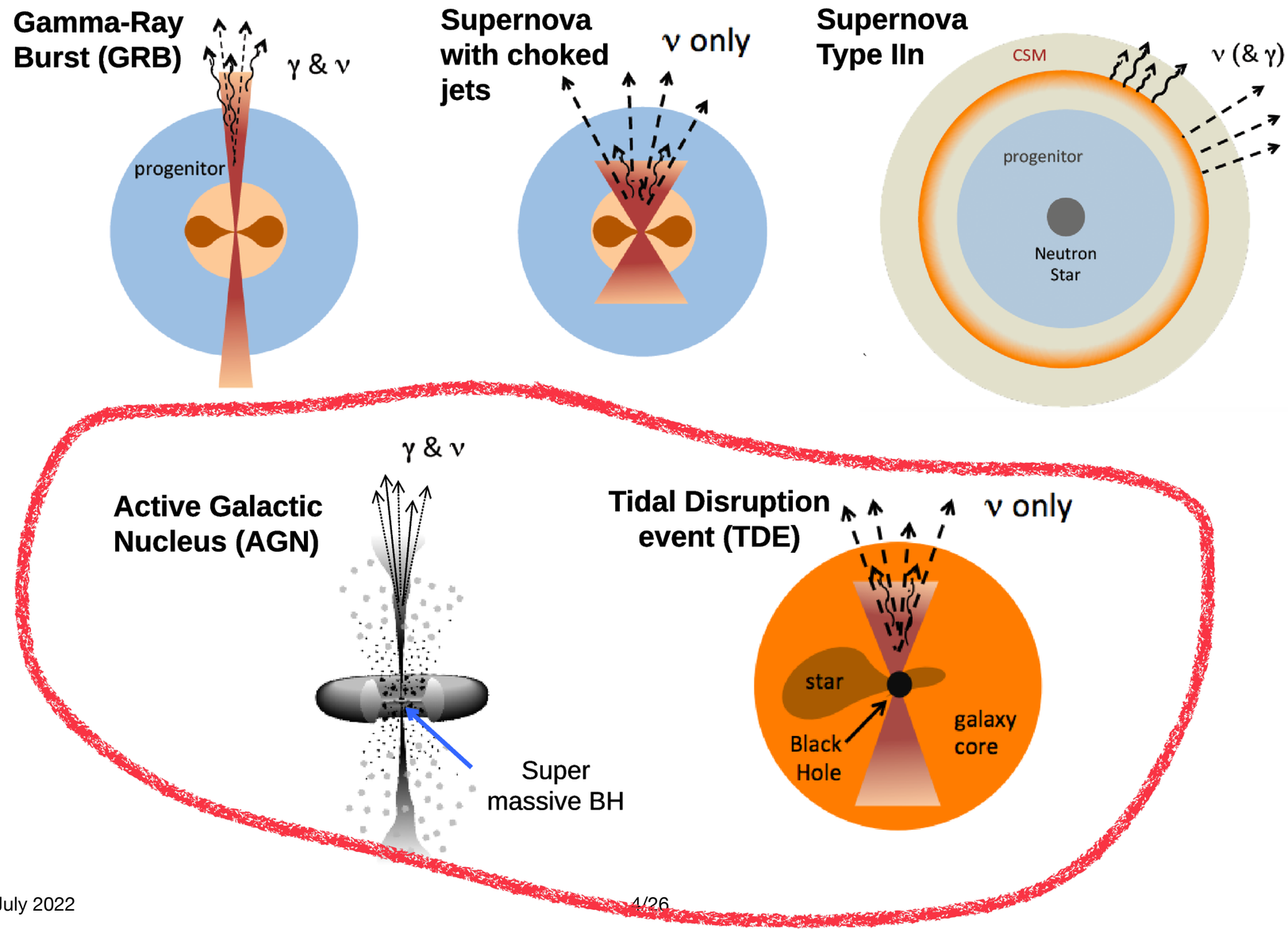


First compelling source: Gamma-ray blazar TXS 0506+056 (2017)

At least 70% of flux: unknown origin

Aartsen et. al. (2015, ApJ), IceCube (2018, Science)

Neutrinos as messengers



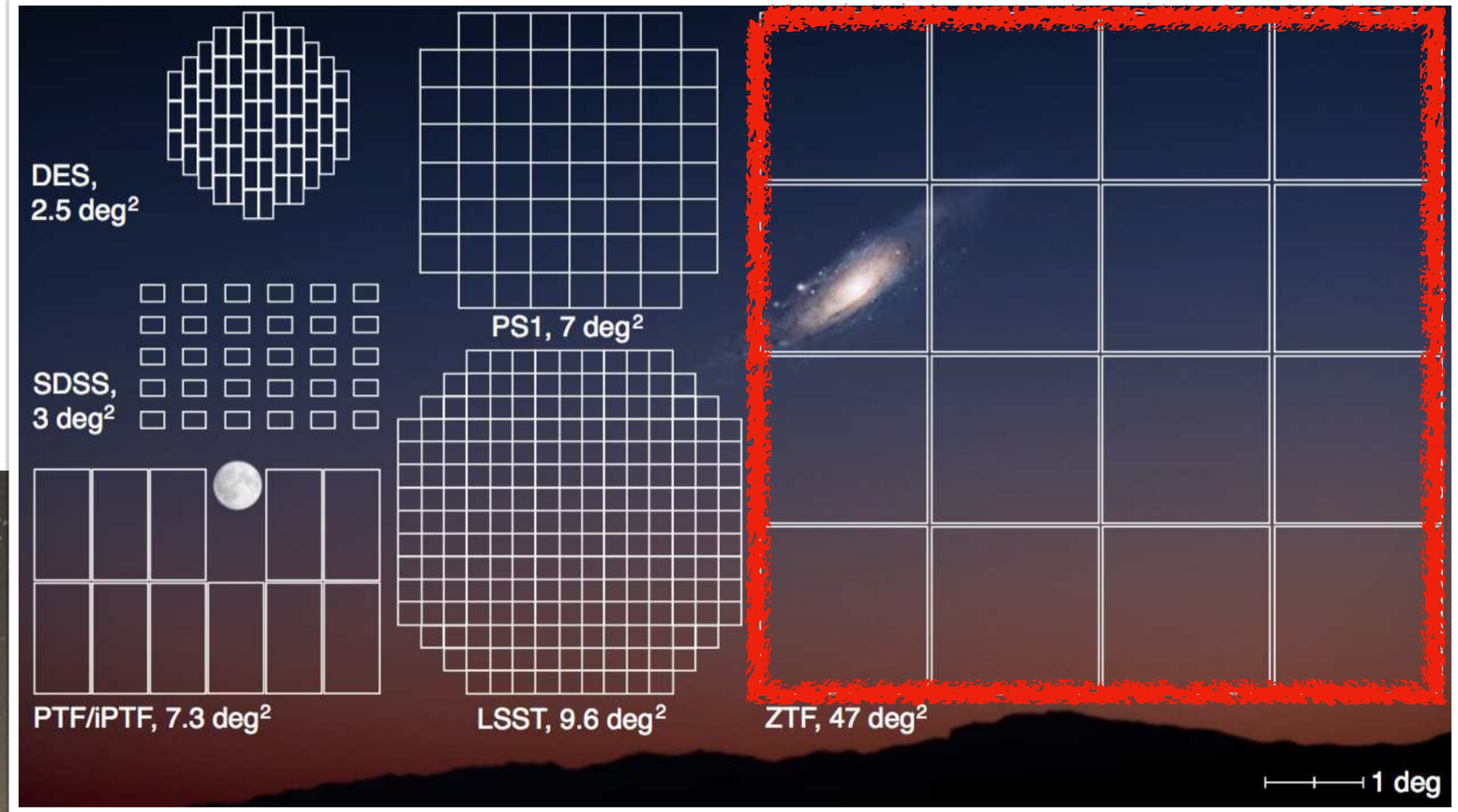
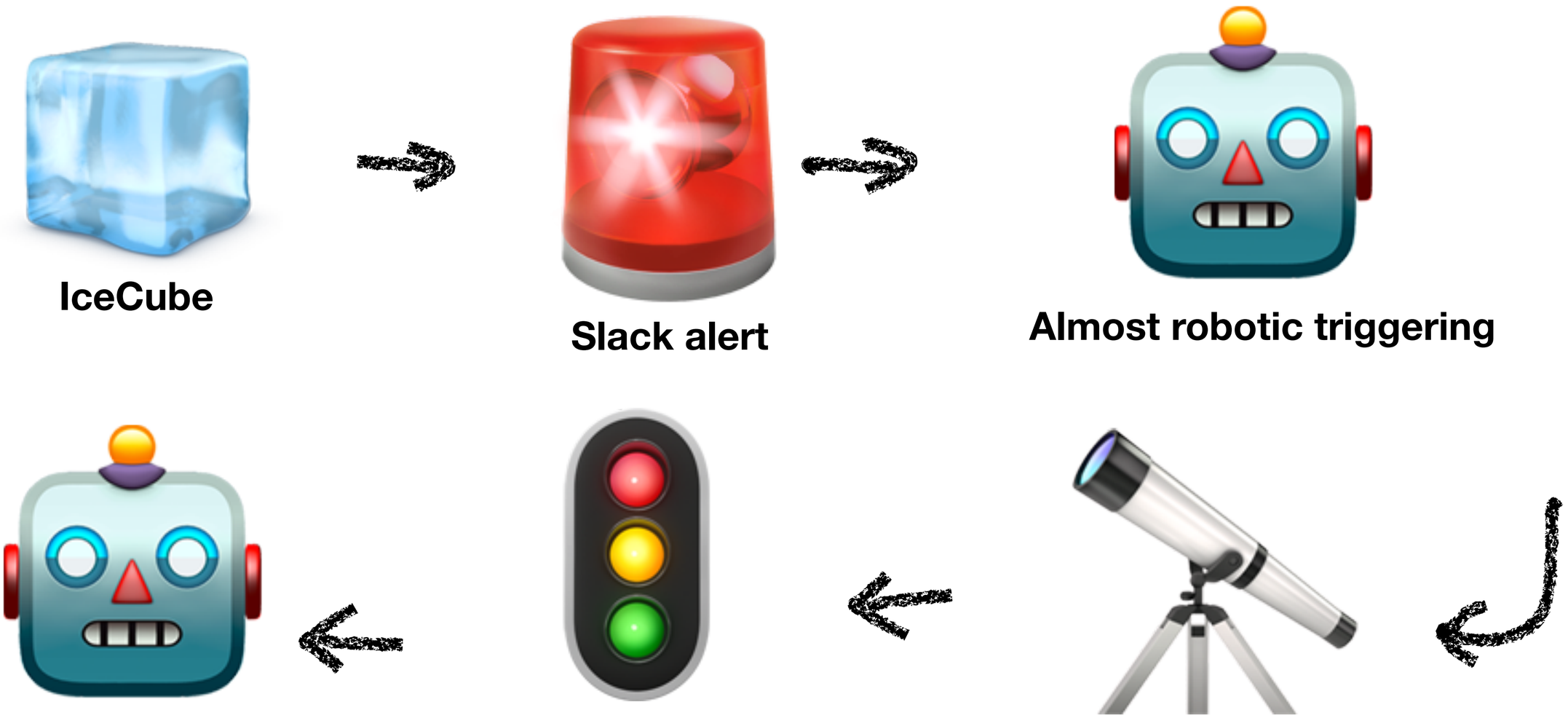
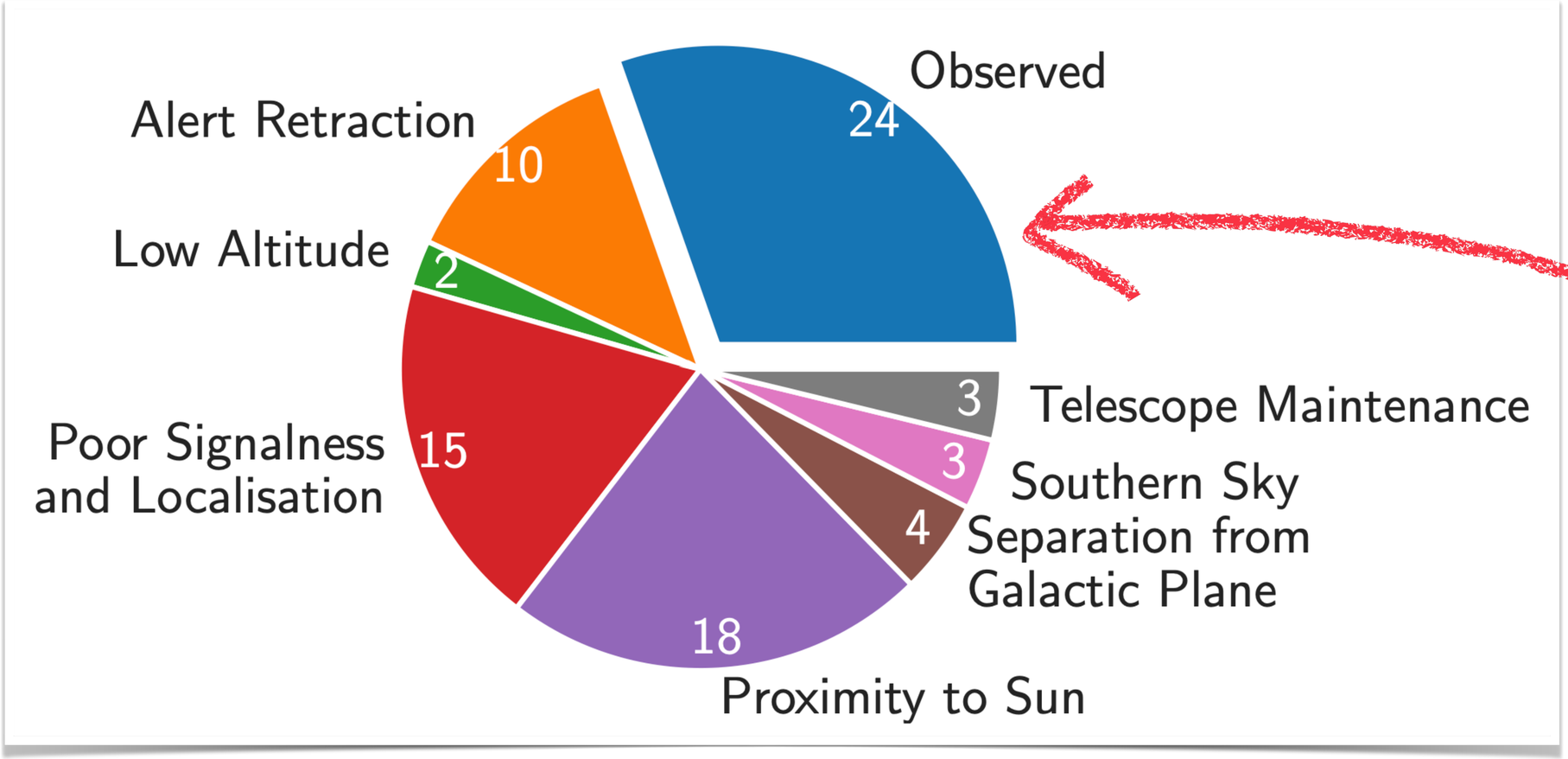


Image credits: Caltech

Our Follow-Up Program



Our Follow-Up Program



We have followed up 32% of non-retracted alerts since 2018

Stein, Reusch et. al. (2022, submitted to MNRAS)

What are Tidal Disruption Events (TDEs)?

Star approaches SMBH

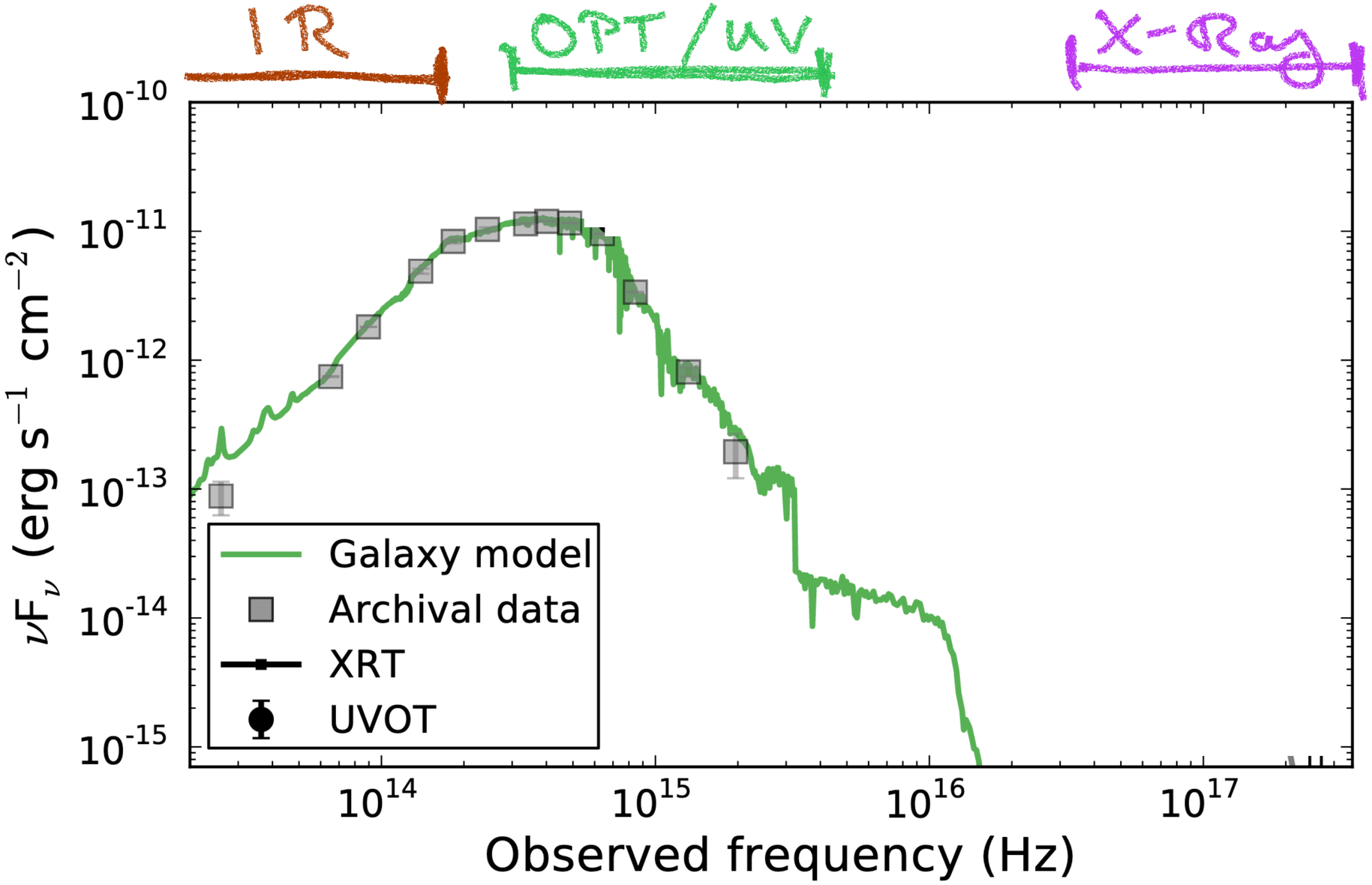
Star is ripped apart by tidal forces

Bright for months!

Star debris gets partially accreted

Image credit: DESY / Science Communication Lab

What are Tidal Disruption Events (TDEs)?



ASASSN-14li: van Velzen et al. (2016, Science)

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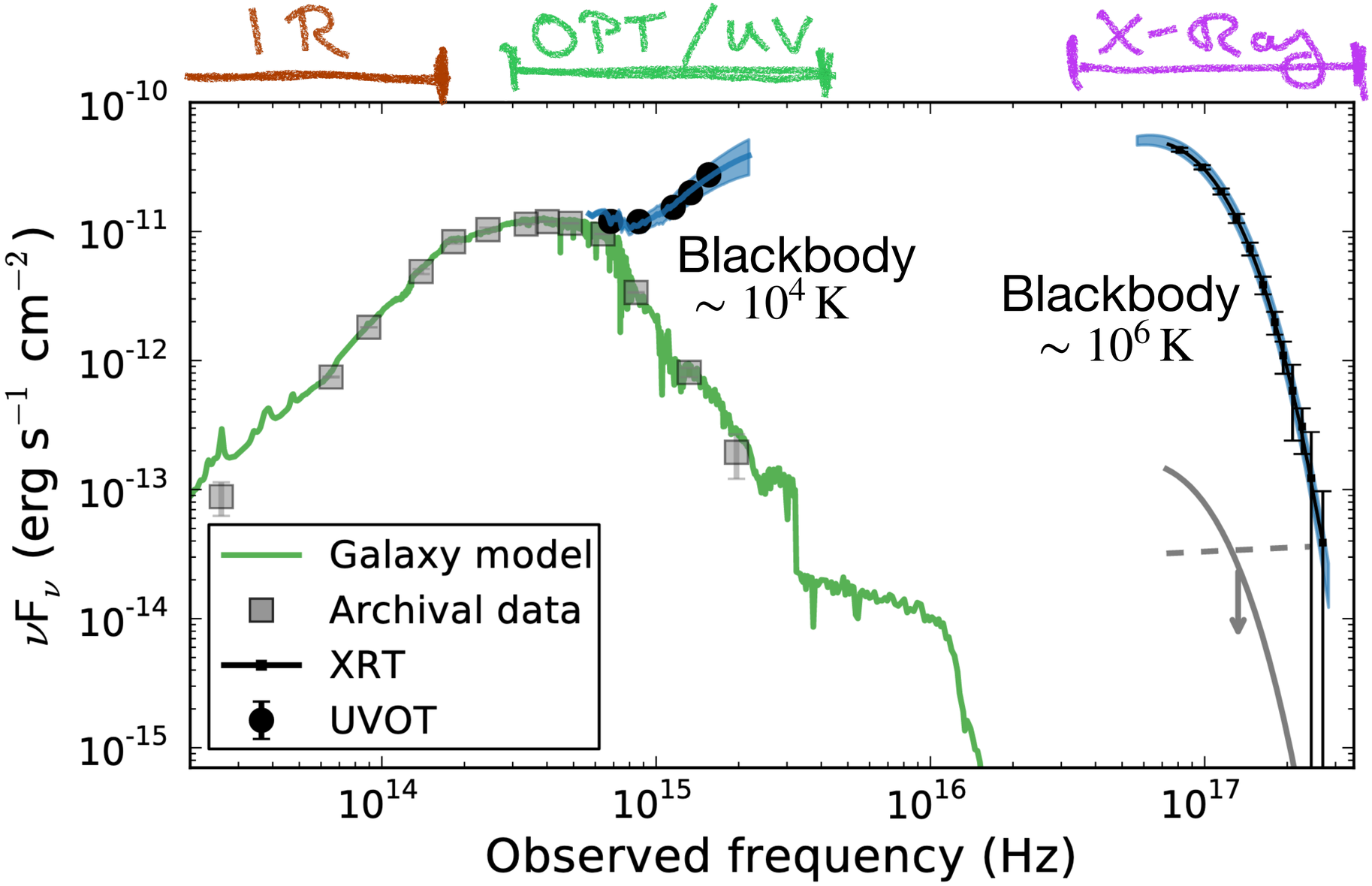
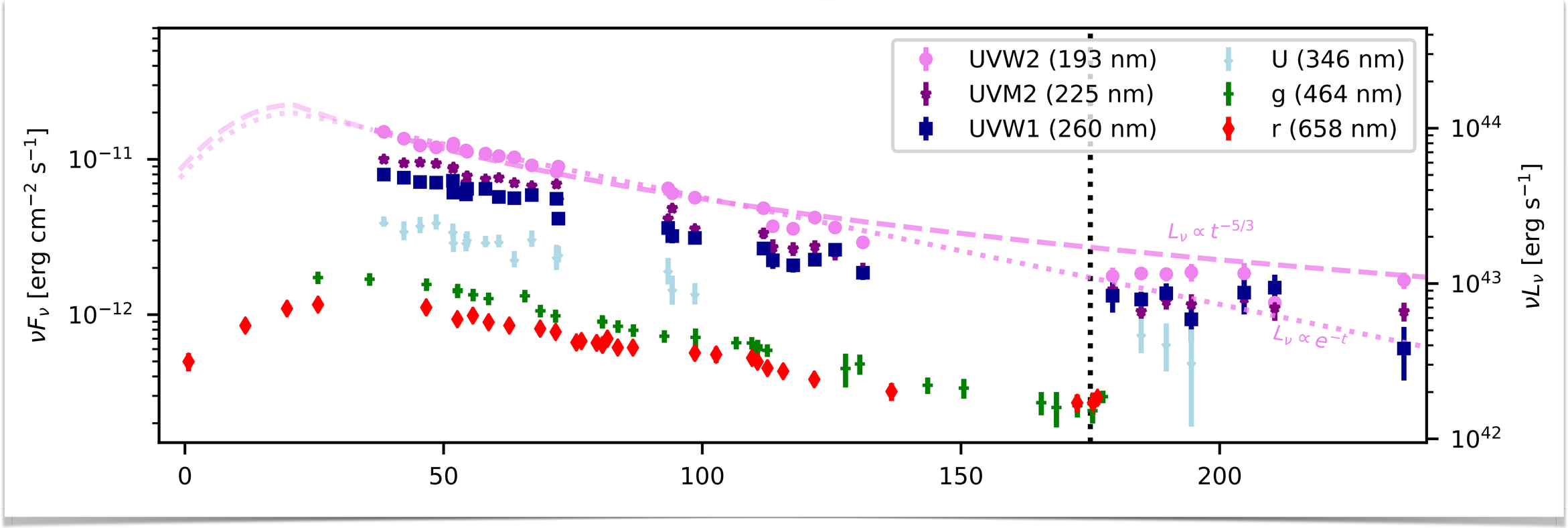


ASASSN-14li: van Velzen et al. (2016, Science)

AT2019dsg: First TDE-neutrino association



Stein et. al. (2021, Nature Astronomy)

AT2019fdr: Second TDE-neutrino association

Nuclear flare, very (!) long-lived

Host: AGN (NLSy1)

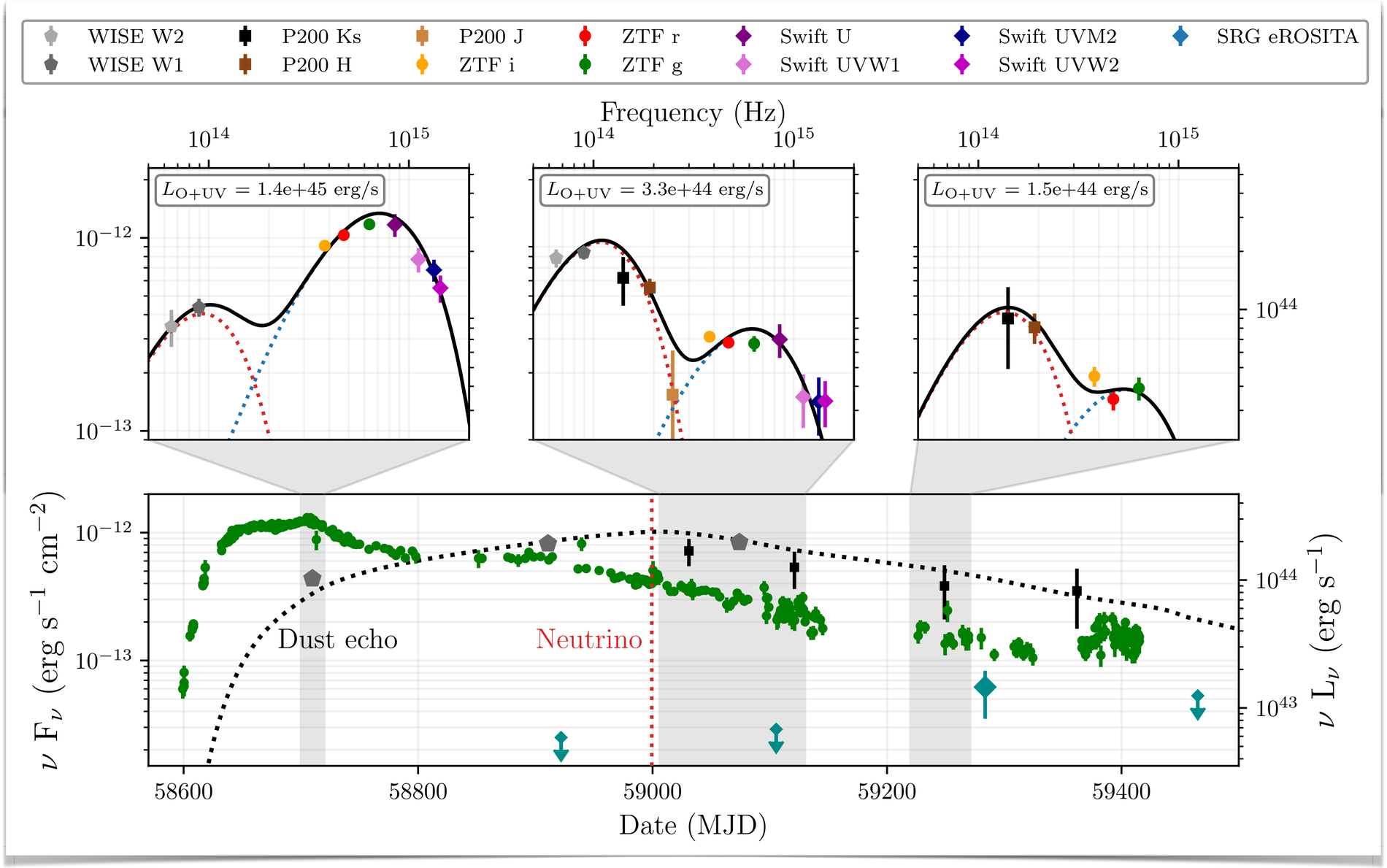
SLSN origin was debated

$$z = 0.267$$

$$M_{\mathrm{SMBH}} = 10^{7.55 \pm 0.13}\ M_{\odot}$$

Reusch et. al. (2022, Phys. Rev. Lett.)

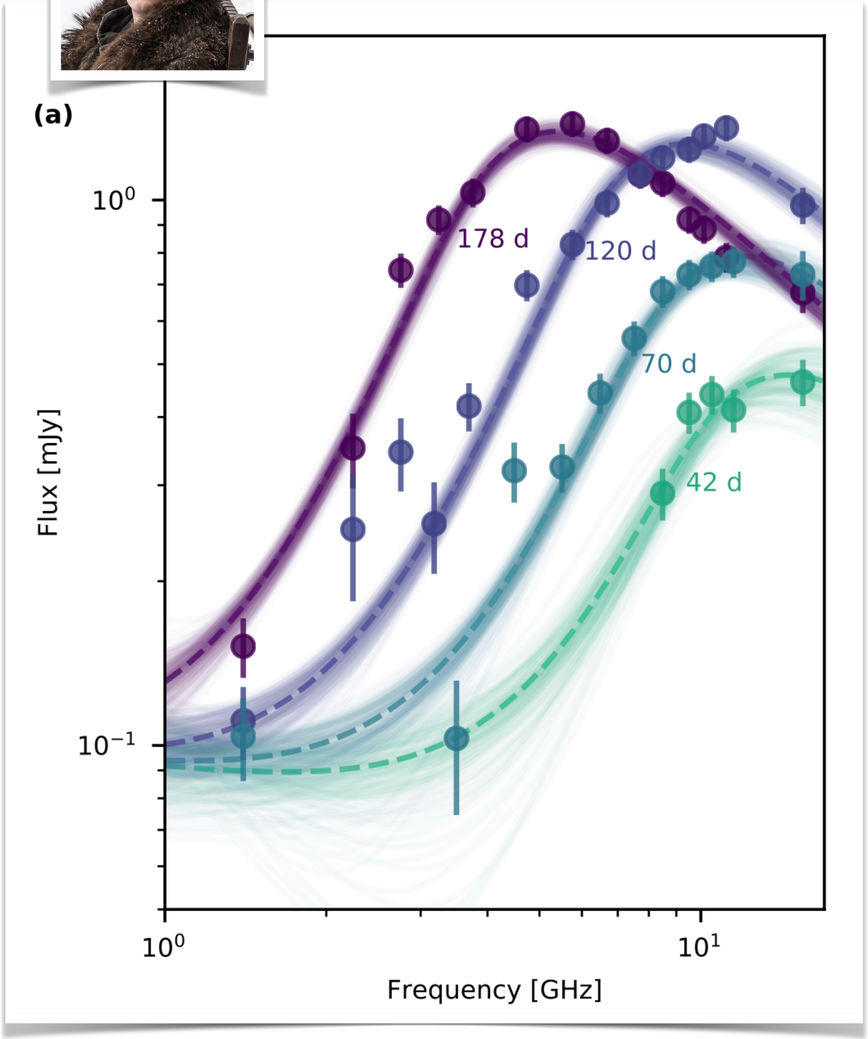
AT2019fdr: Second TDE-neutrino association



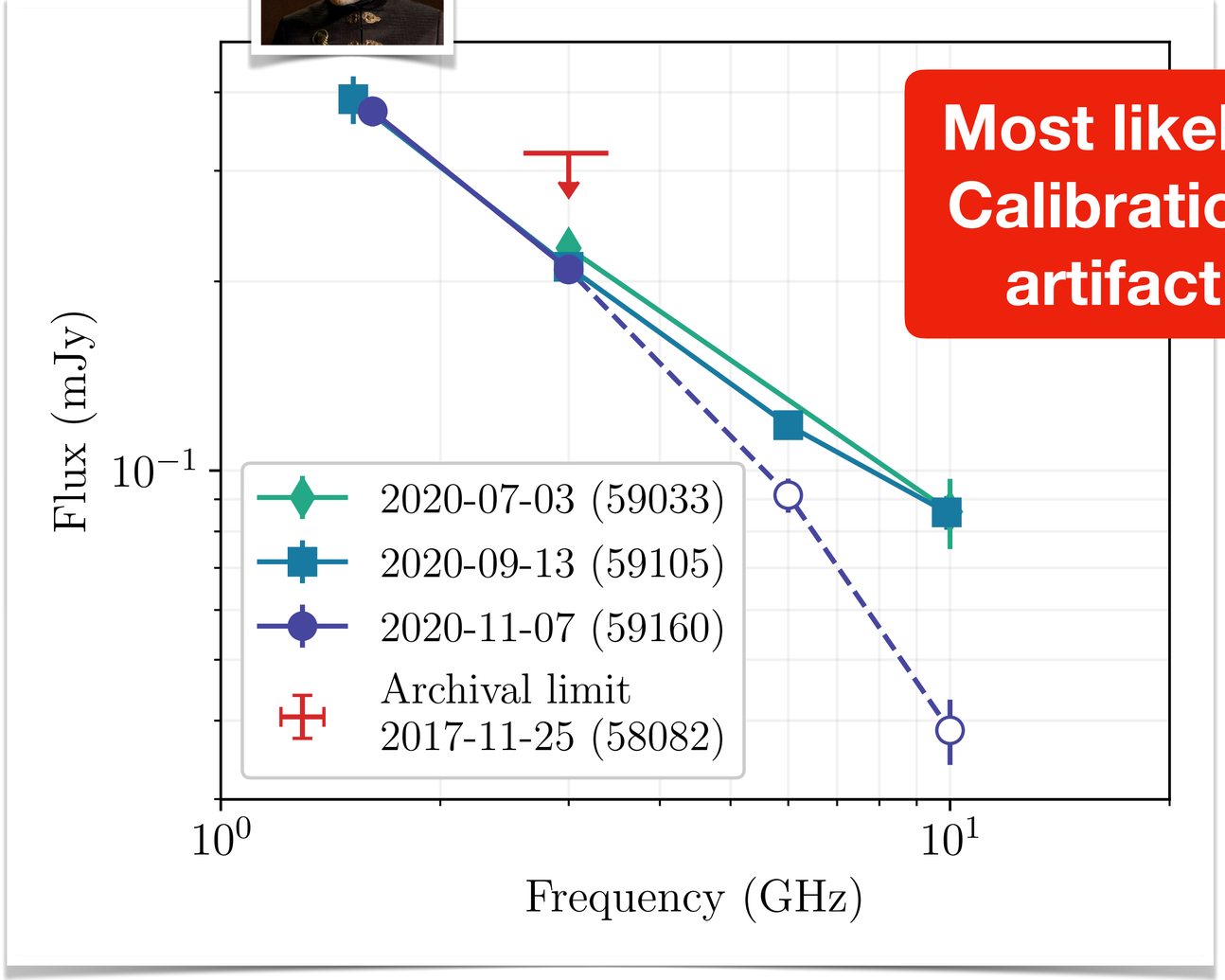
Reusch et. al. (2022, Phys. Rev. Lett.)

Radio observations (VLA)

AT2019dsg



AT2019fdr



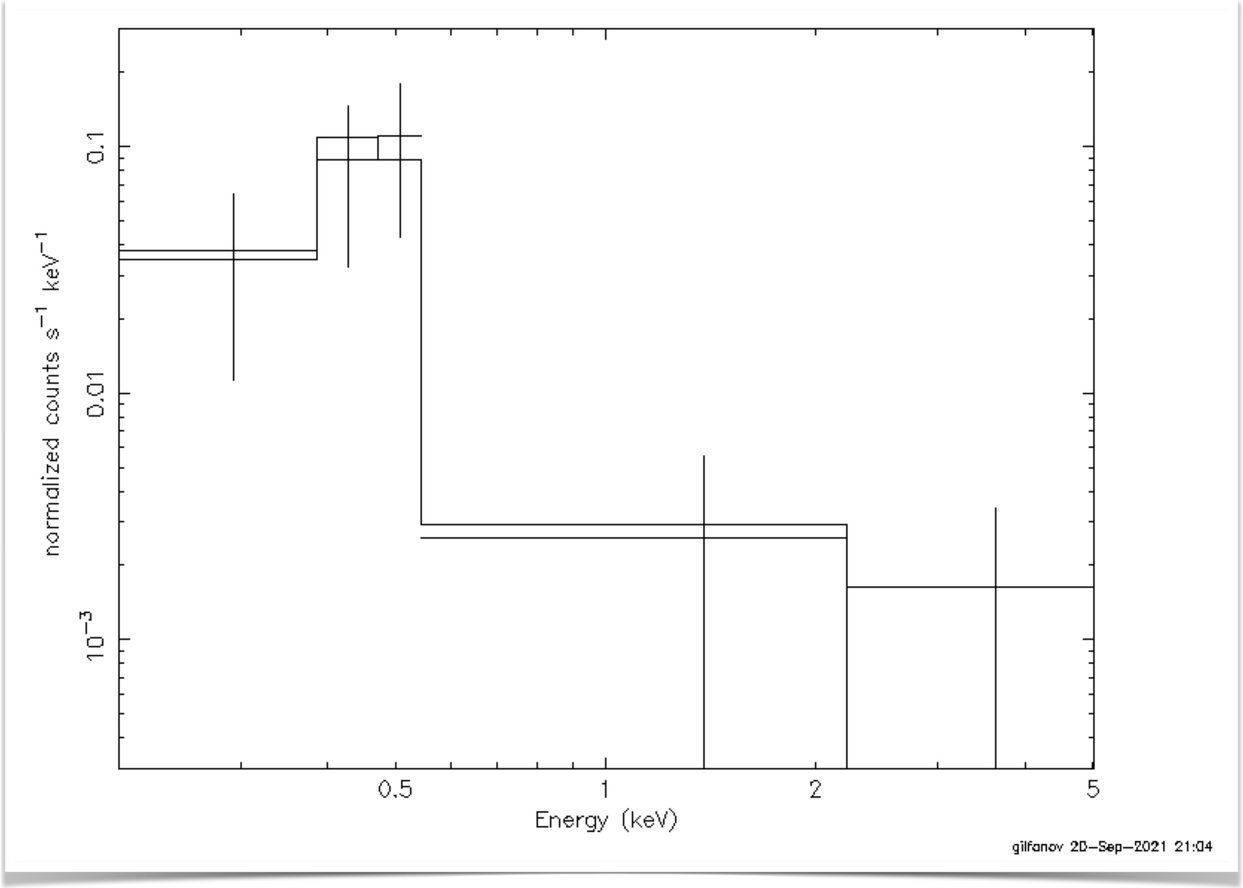
Most likely: Calibration artifact

Stein et. al. (2021, Nature Astronomy), Reusch et. al. (2022, Phys. Rev. Lett.)

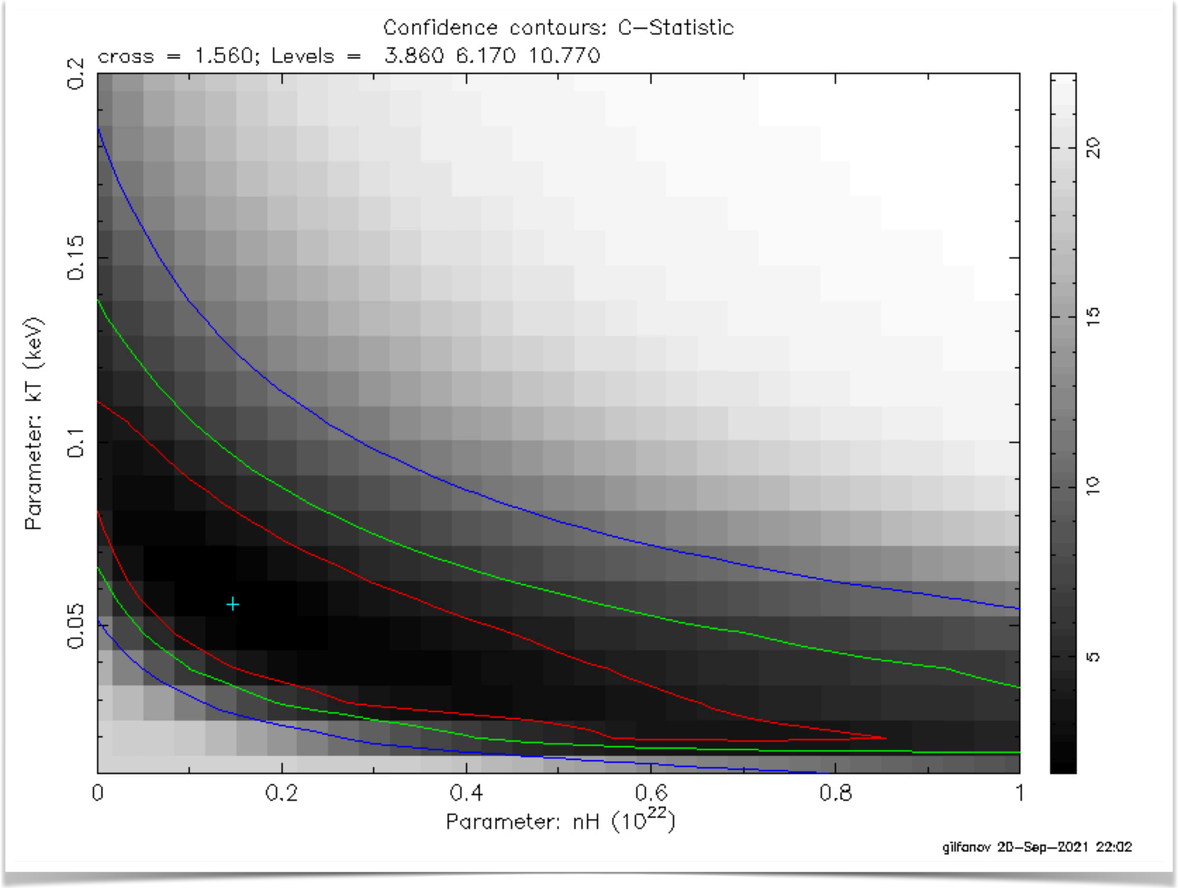
X-ray observations (SRG/eROSITA)

Detected on the third visit

Soft spectrum



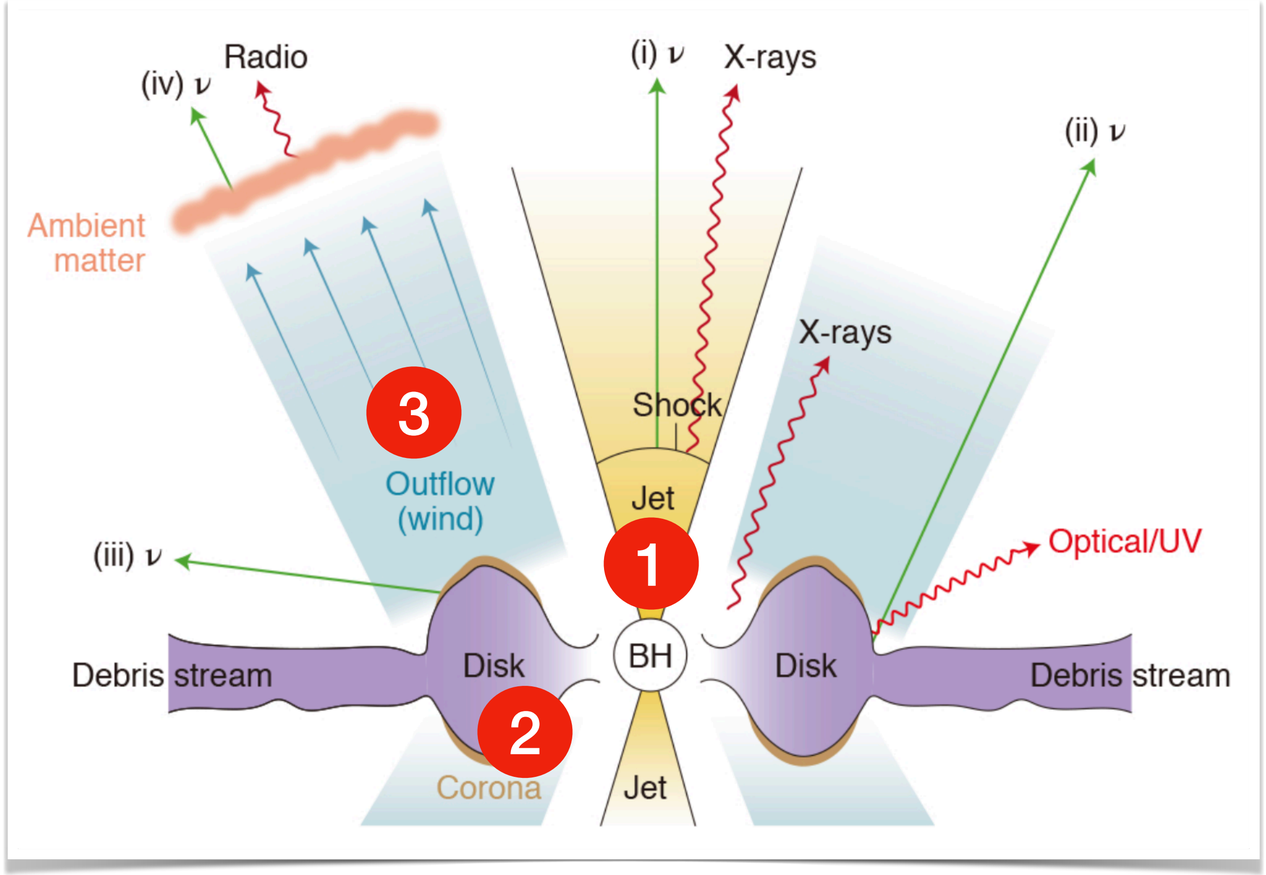
Temperature fit: $71\ \mathrm{eV}$

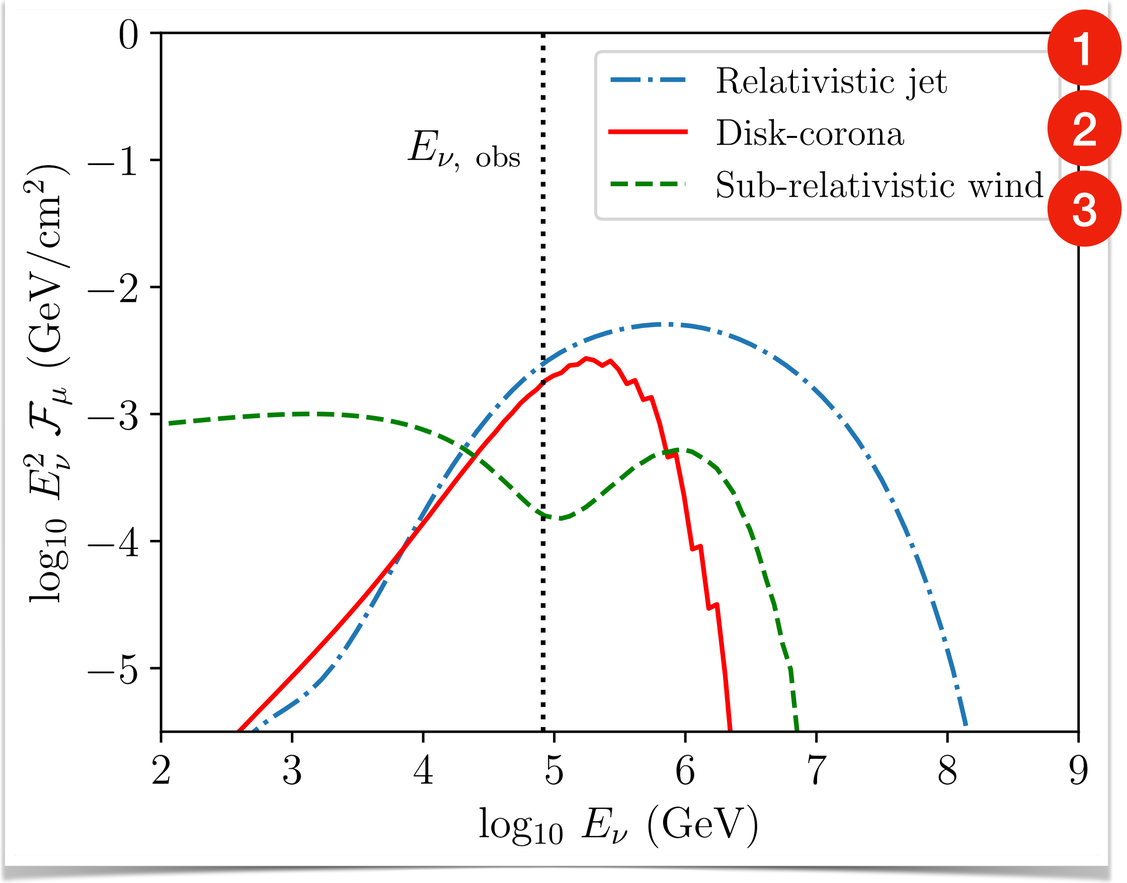


AT2019fdr neutrino spectra

TDEs suggested as sources of HE neutrinos:

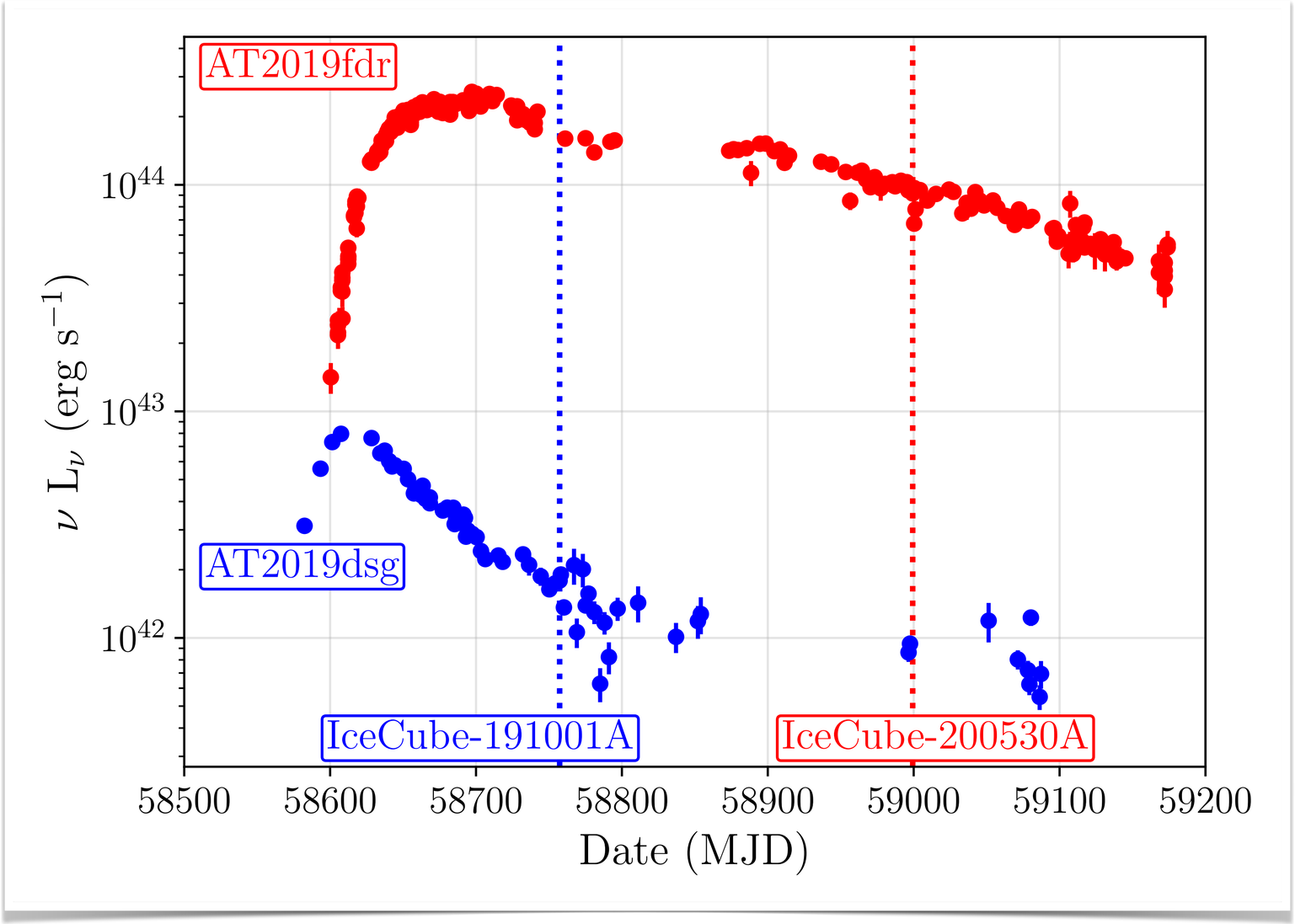
Dai & Fang (2017, MNRAS)
Hayasaki & Yamazaki (2019, ApJ)
Winter & Lunardini (2017, Phys. Rev. D)





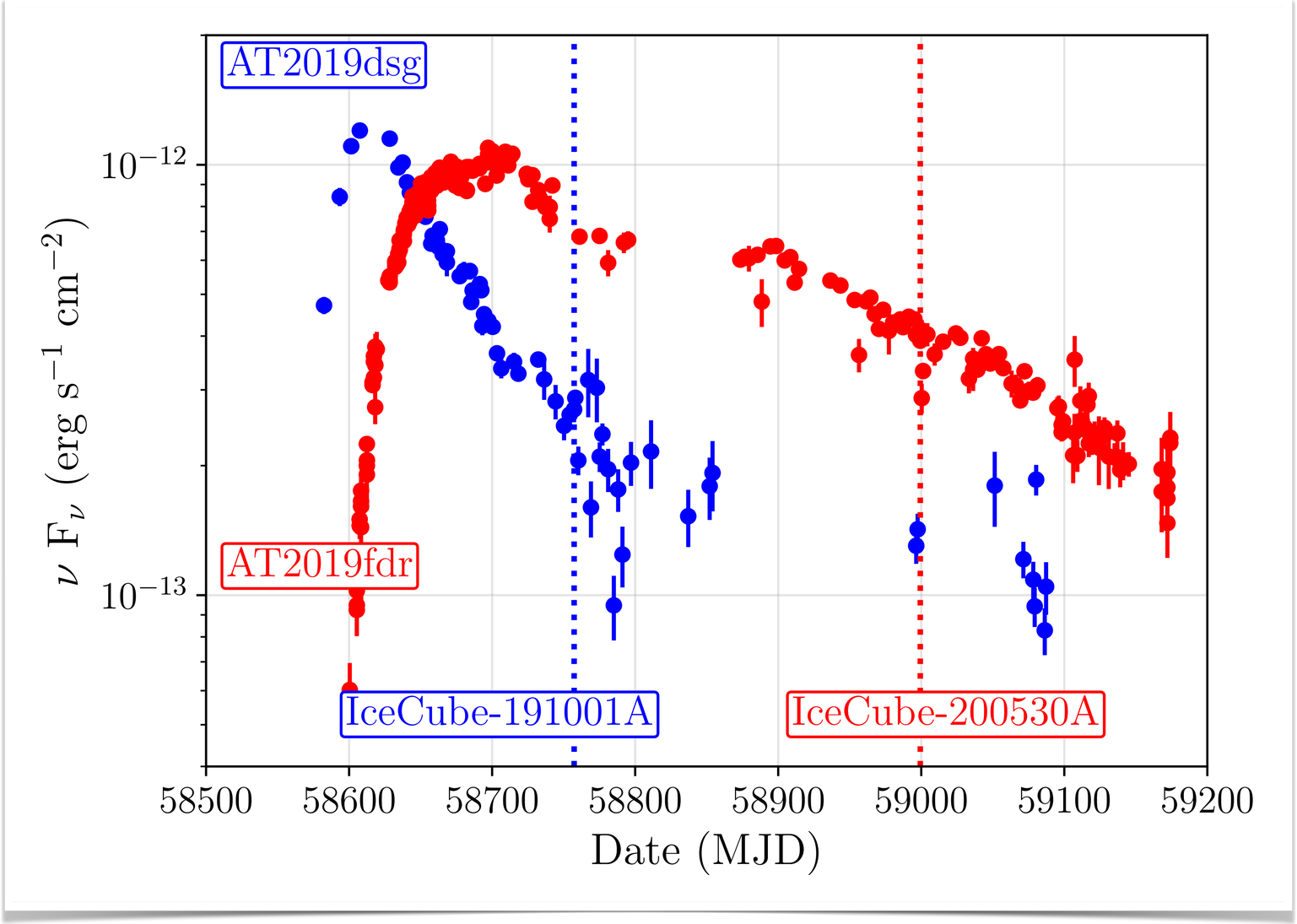
Hayasaki (2021, Nat. Astron.), Reusch et. al. (2022, Phys. Rev. Lett.)

Luminosity comparison



Luminosity of AT2019fdr much higher

Flux comparison



But comparable flux on earth

Comparison

	AT2019dsg	AT2019fdr
TDE	yes	likely
Peak Luminosity	$3.5 \times 10^{44}\,\mathrm{erg\,s^{-1}}$	$1.3 \times 10^{45}\,\mathrm{erg\,s^{-1}}$
SMBH Mass	$10^{6} - 10^{6.7}\ M_{\odot}$	$10^{7.55\pm0.13}\ M_{\odot}$
Radio	evolving	non-evolving
UV	very bright	bright
X-ray	early, soft spectrum	late, soft spectrum
Dust echo	very strong	strong
Neutrino delay	~ 5 months	~ 10 months
nu production?	yes	yes

Combined population:

Confirmed TDEs + accretion flares

Brightness + rise/fade-time cuts

Combined chance coincidence:

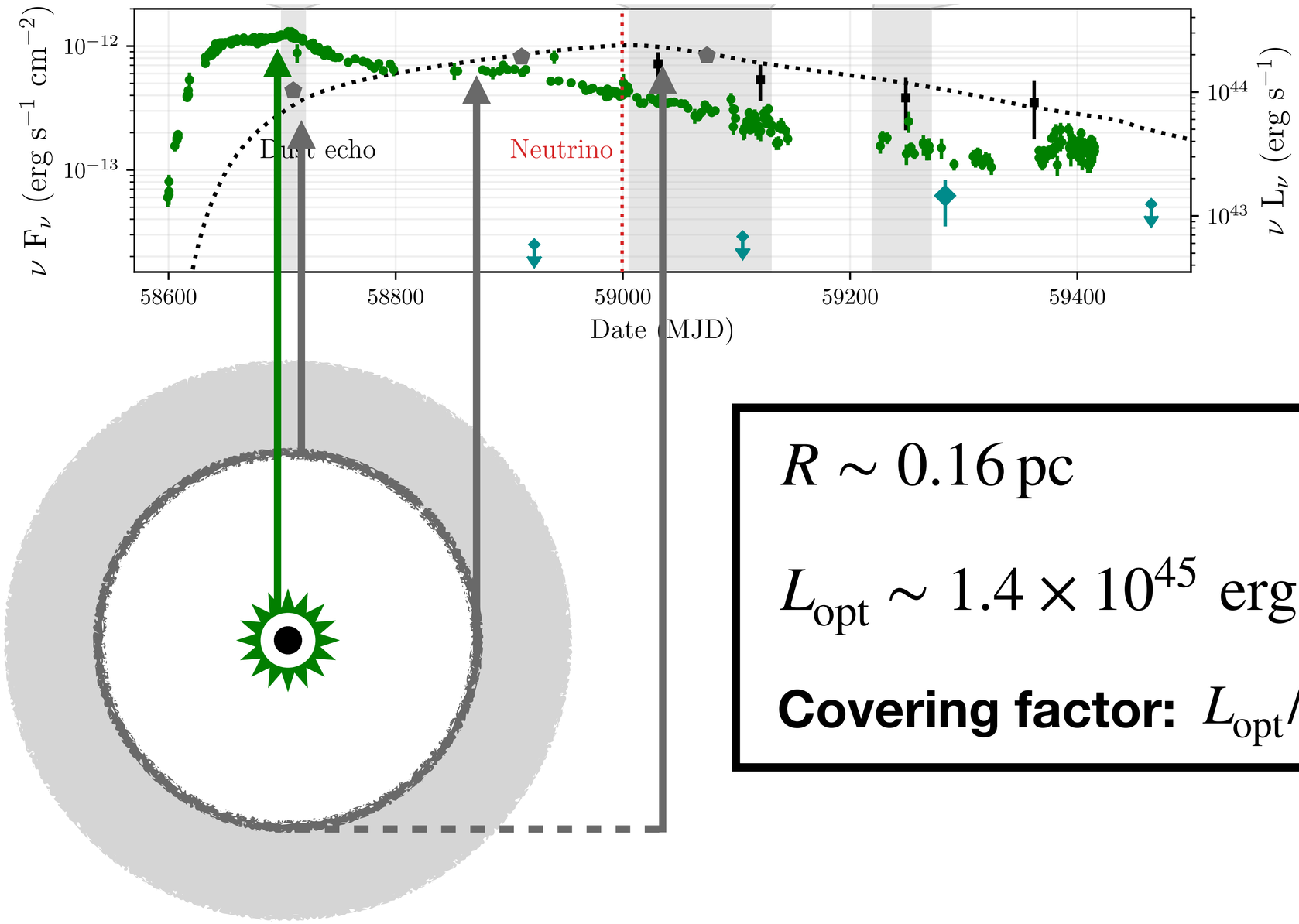
$p = 3.44 \times 10^{-4}\ (3.4\,\sigma)$

Dust echo

Image credit: DESY / Science Communication Lab

Dust echo

AT2019fdr



ZTF g

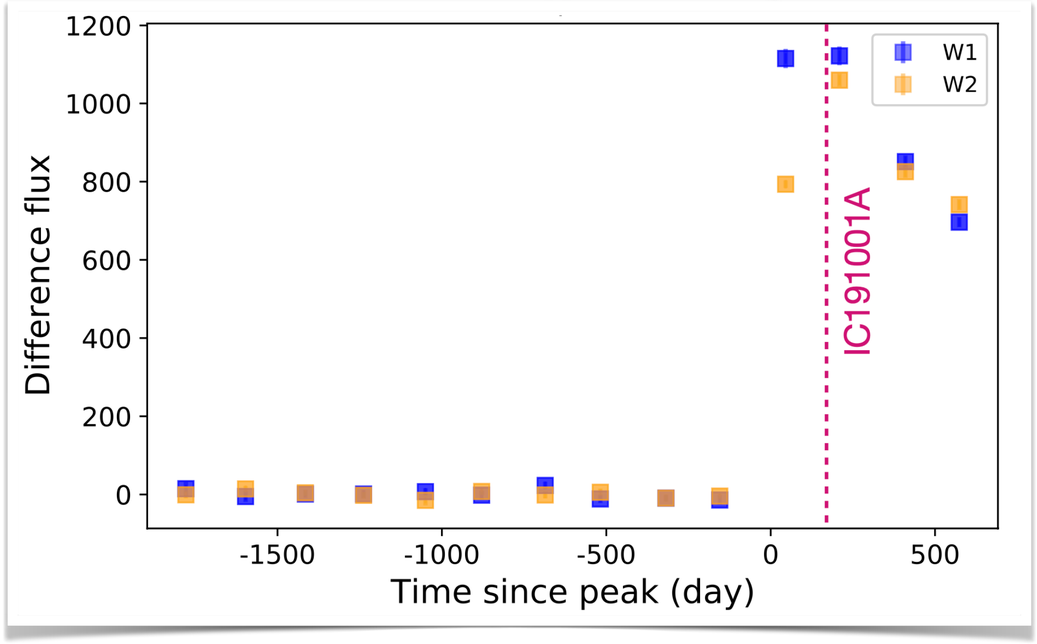
WISE W1

$R \sim 0.16\,\mathrm{pc}$

$L_{\mathrm{opt}} \sim 1.4 \times 10^{45}\ \mathrm{erg\ s^{-1}}$

Covering factor: $L_{\mathrm{opt}}/L_{\mathrm{dust}} \sim 33\,\%$

AT2019dsg () had a record-breaking dust echo

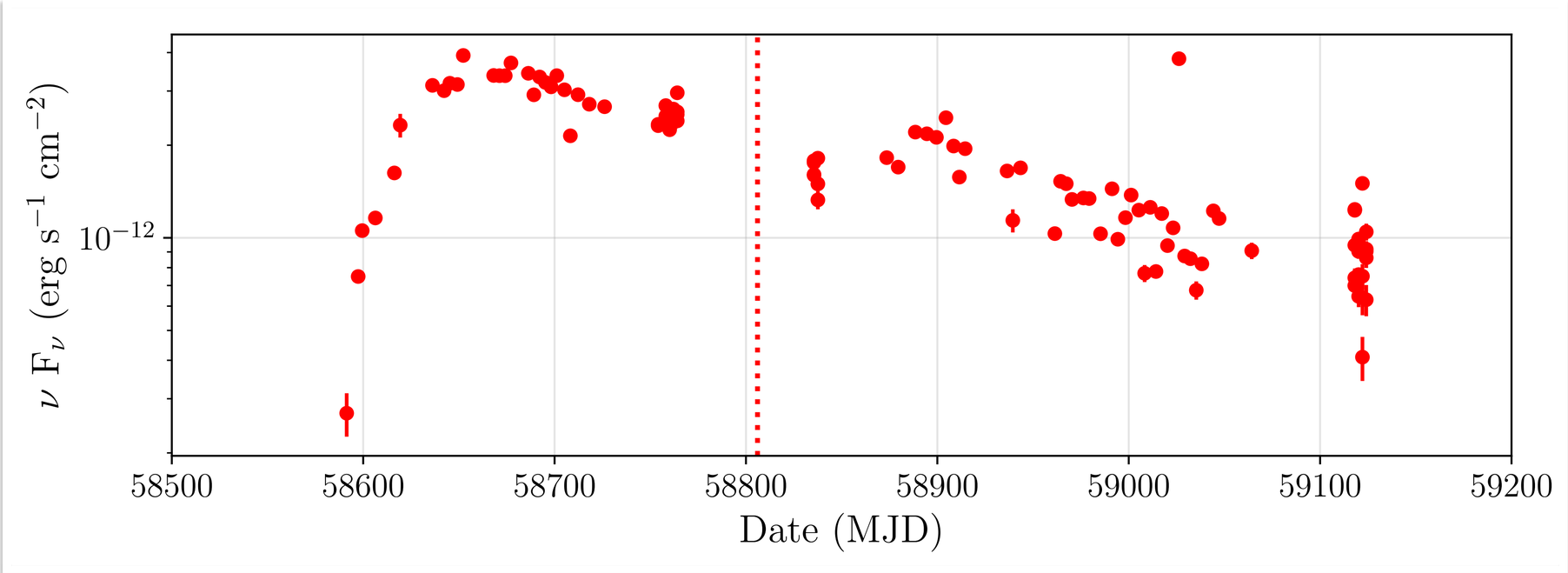


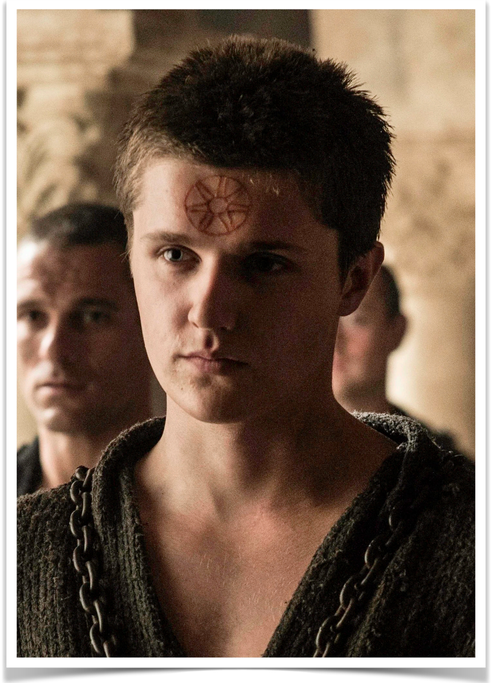
AT2019fdr () also has a strong dust echo

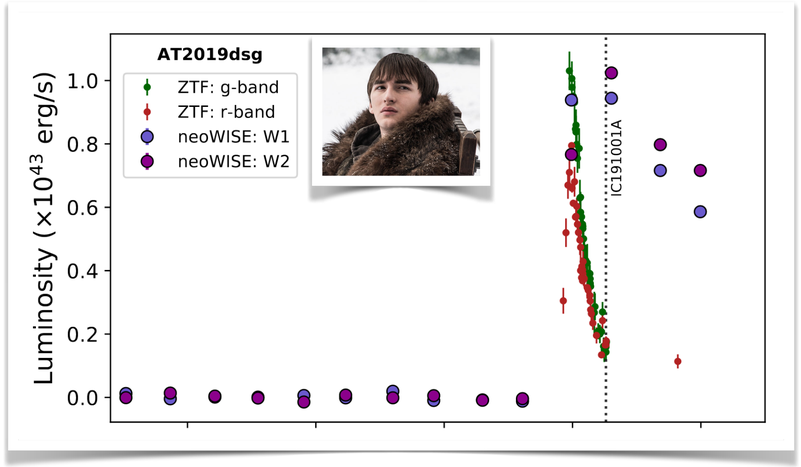
AT2019aalc: A third association

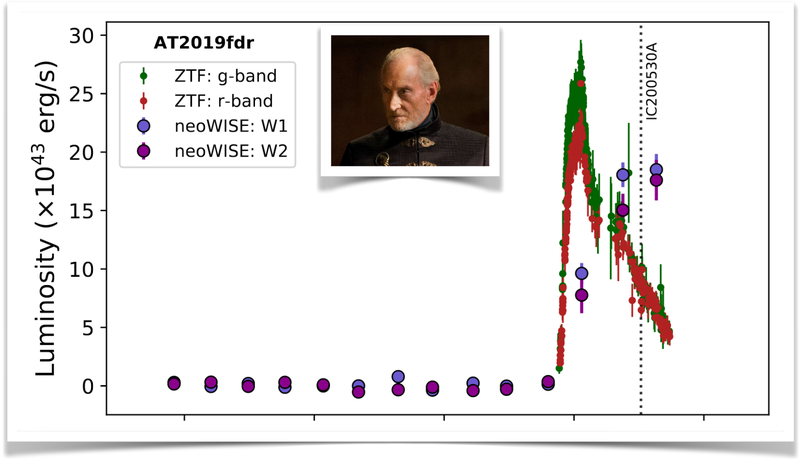
Systematic search for coincidence between IceCube public alerts and optical flares that show post-peak neoWISE infrared flares

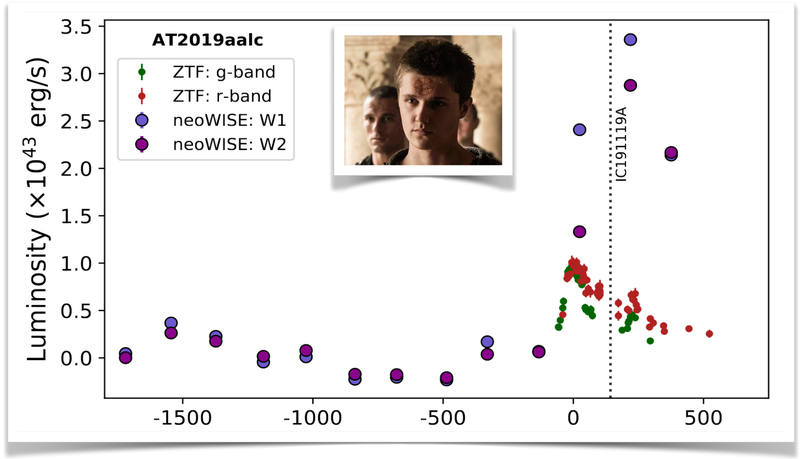
van Velzen et. al. (2021, submitted to Science)









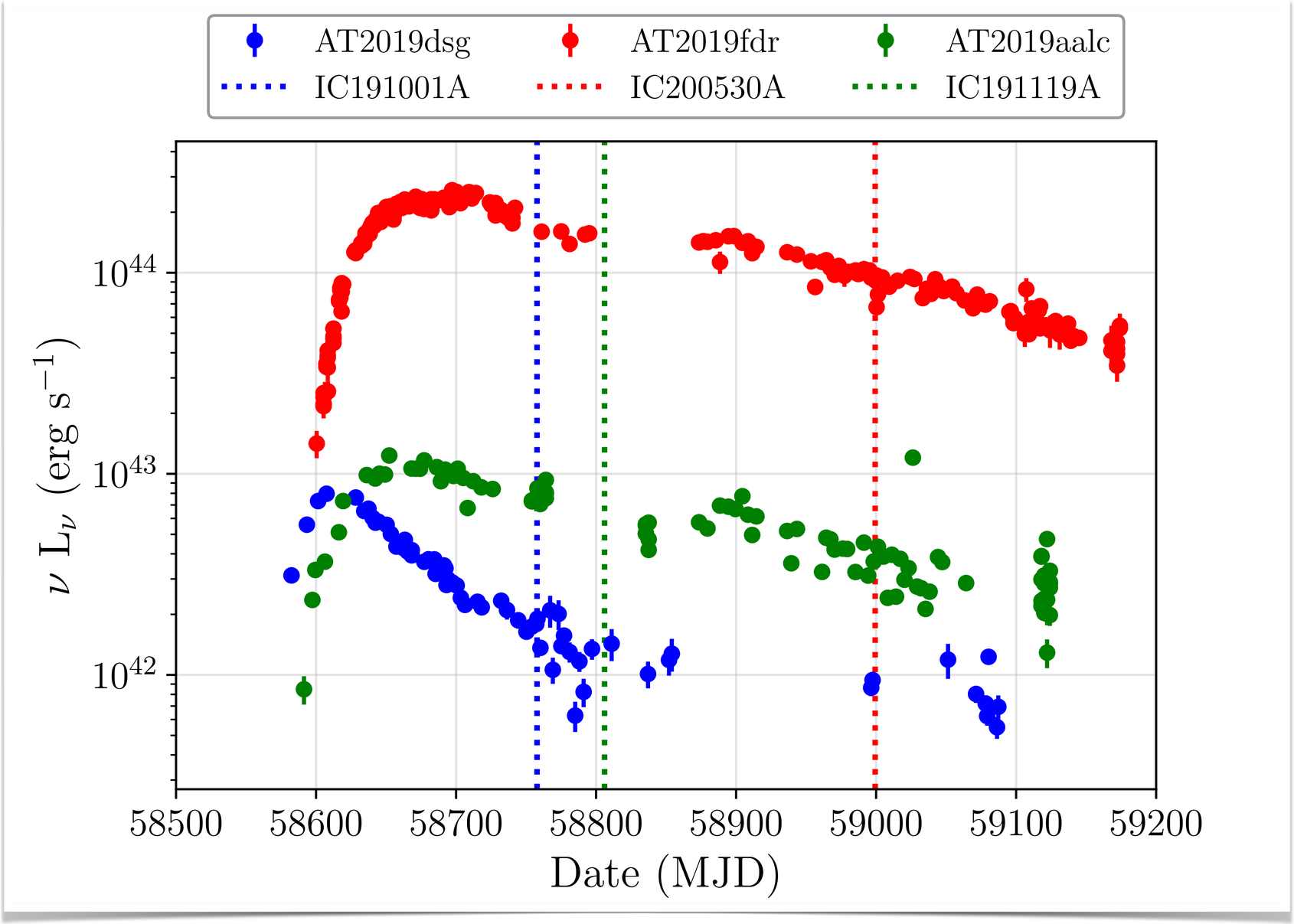


All have strong dust echo

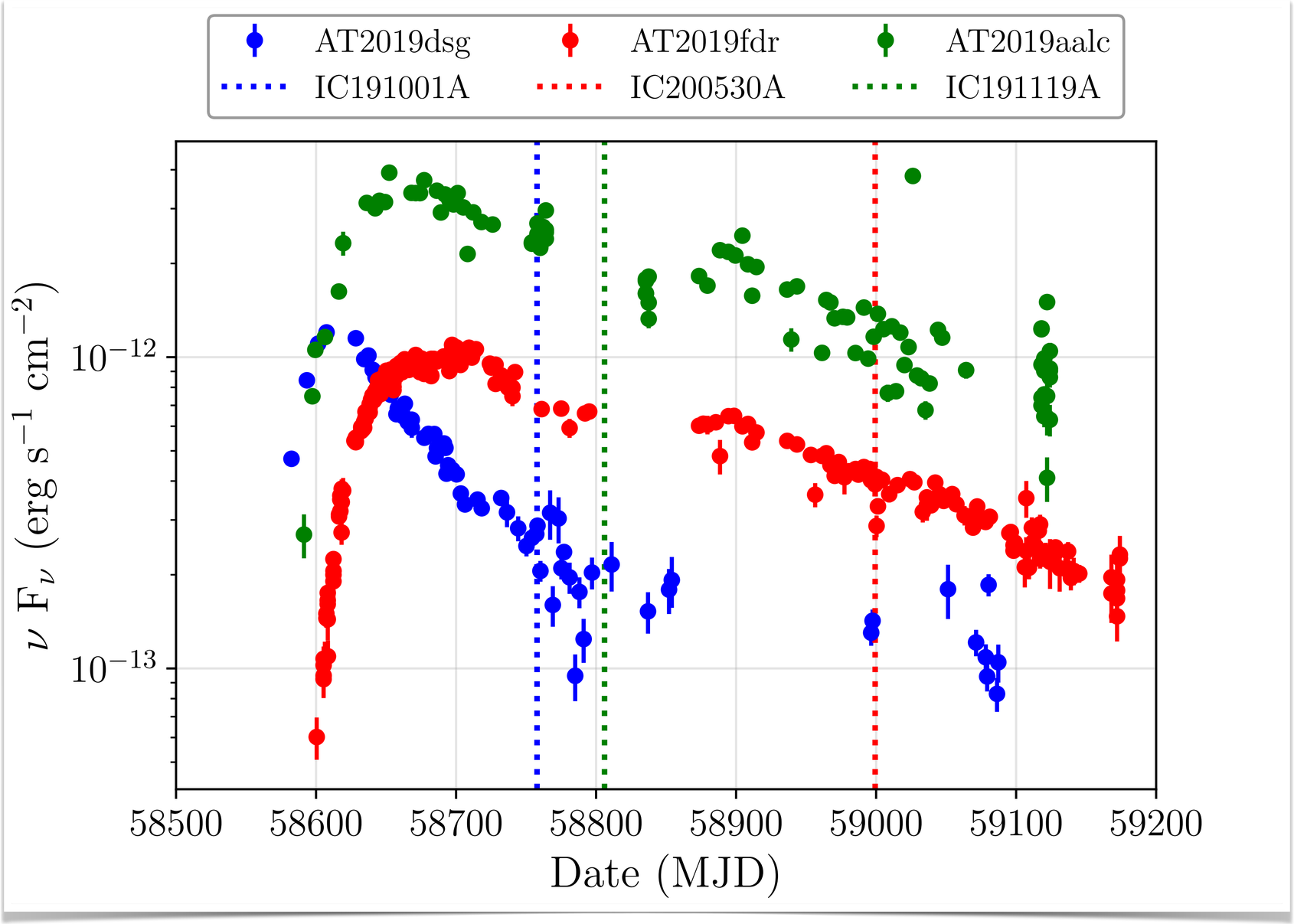
All have soft X-ray spectrum

All were detected in radio

Luminosity comparison

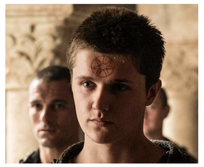


Flux comparison



Comparison





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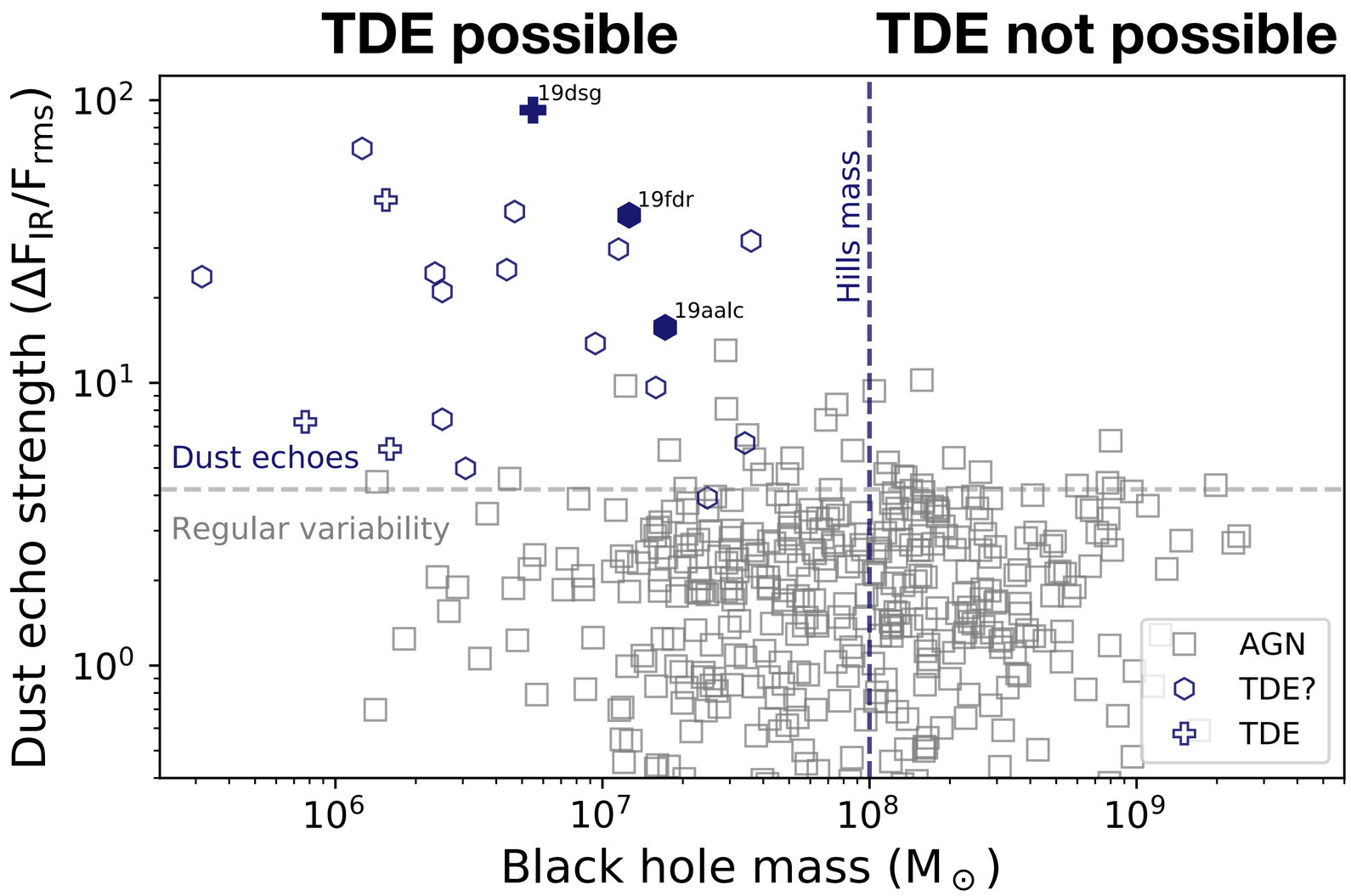
X-ray	early, soft spectrum	late, soft spectrum	soft spectrum
Dust echo	very strong	strong	very strong
Neutrino delay	~ 5 months	~ 10 months	~ 5 months
nu production?	yes	yes	?

$$p = 2 \times 10^{-4}\ (3.7\,\sigma)$$

Maybe they are a unified population



van Velzen et. al. (2021, submitted to Science)

Conclusion

These three associated events could produce a significant part of the IceCube high-energy neutrino flux (>7%)

“Normal” AGN outshine TDEs by a two orders of magnitude, we should be dominated by those

—> very efficient neutrino production in TDEs?

Stacking Analysis

Systematic stacking analysis of dust-echo sample led by Jannis Necker (DESY)

Same source sample as study above, but + low-energy neutrinos

Jannis will give a talk at TeVPA about this

Well, the universe will (hopefully) tell us more

Continue realtime follow-up!

Systematic study of "nuclear" ZTF sample + IR WISE sample

LSST looming on the horizon 🎉

Image Credit: Rubin Observatory

Summary

- **Follow-up campaign ongoing since over 3 years**
- **Three events found in coincidence with IceCube alerts**
- **Systematic analysis of dust echoes due to accretion flares**
- $p = 2 \times 10^{-4}$ $(3.7\,\sigma)$**, based only on IR properties**