
JSI JOINT SPACE-SCIENCE INSTITUTE
NASA
Discovering rare transients and multi-messenger counterparts with the Zwicky Transient Facility
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Neil Gehrels Fellow
Oskar Klein Center
October 17, 2023
Image credit: DESY

The transient sky

Walter Baade

Fritz Zwicky

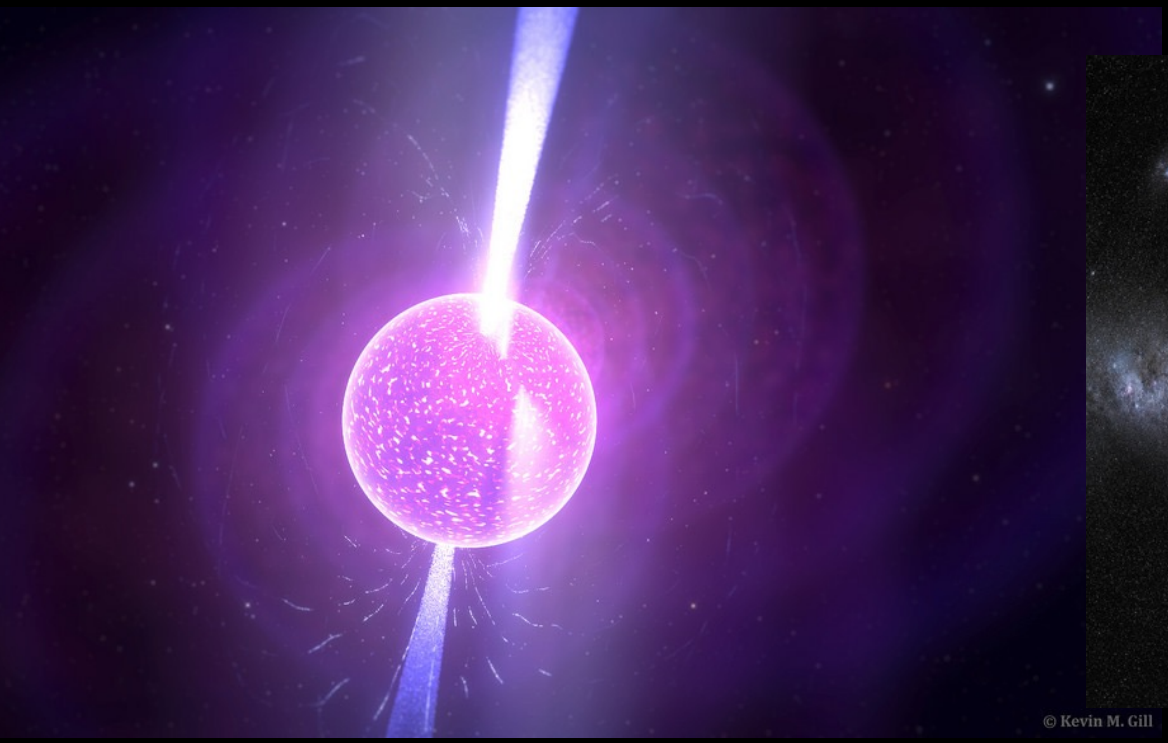
"The modern era of transients with controlled cadence and a physics-based enquiry began with F. Zwicky and W. Baade."

Kulkarni (2012), "*Cosmic Explosions*"

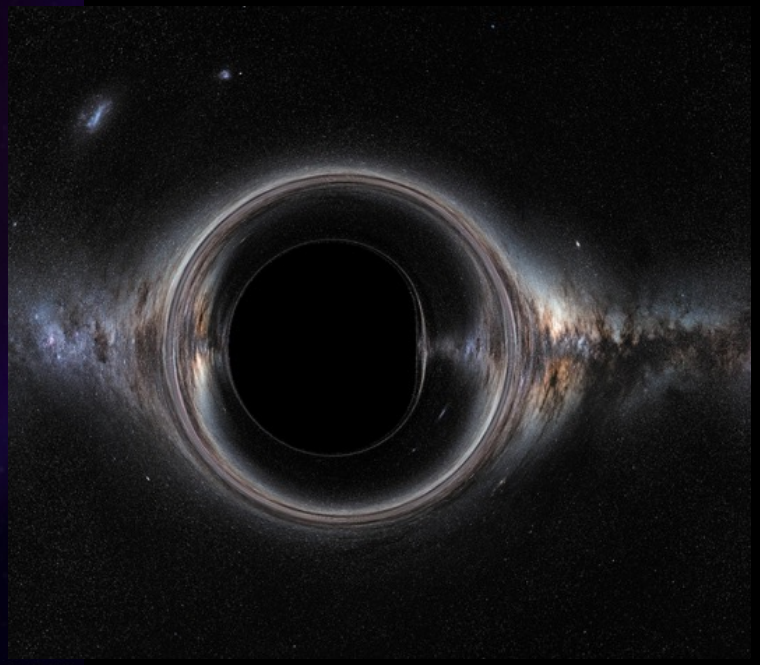
Death of massive stars

What is left after the explosion?

Neutron star

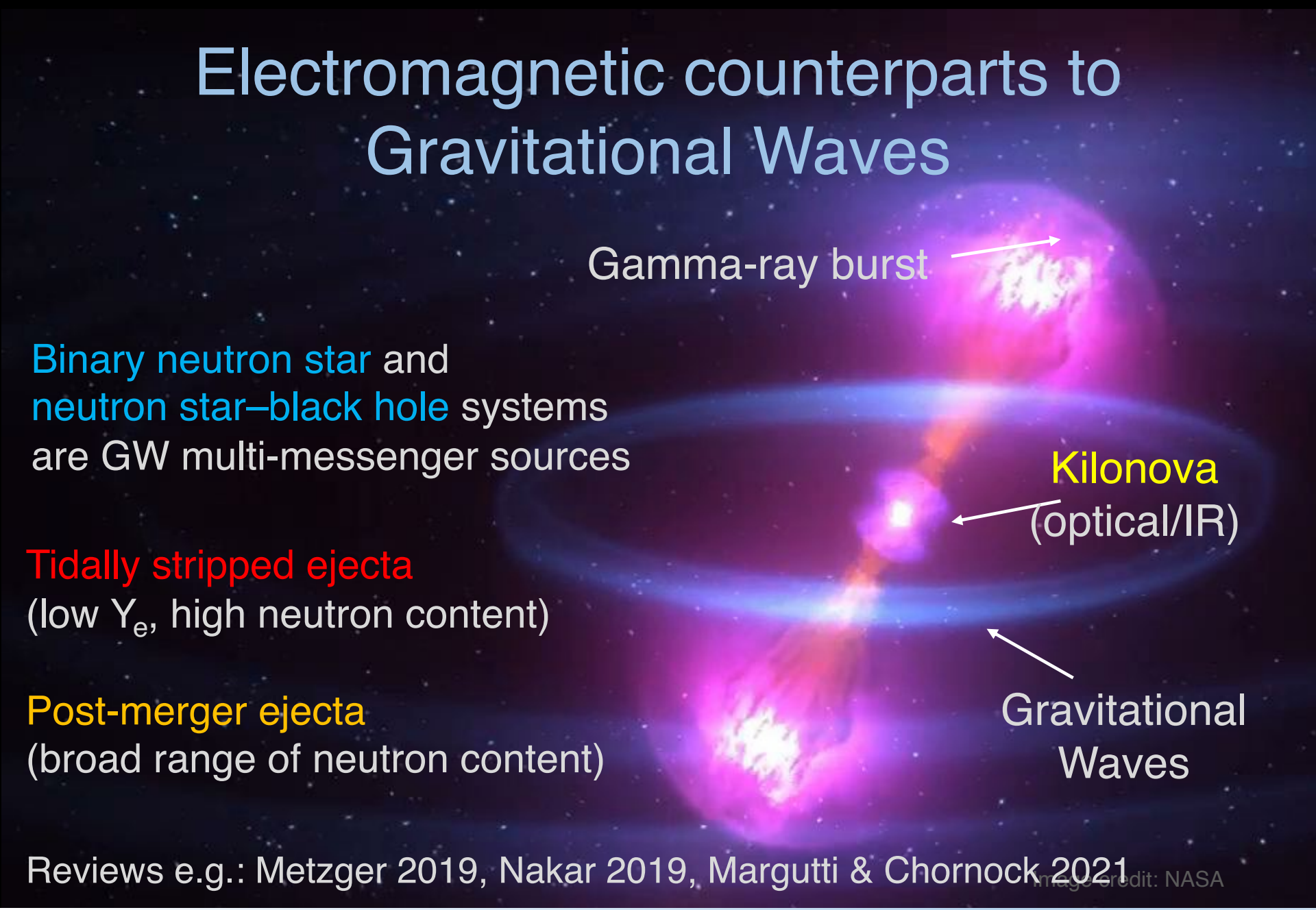


Black hole



credit: ESO

Electromagnetic counterparts to Gravitational Waves



Binary neutron star and
neutron star–black hole systems
are GW multi-messenger sources

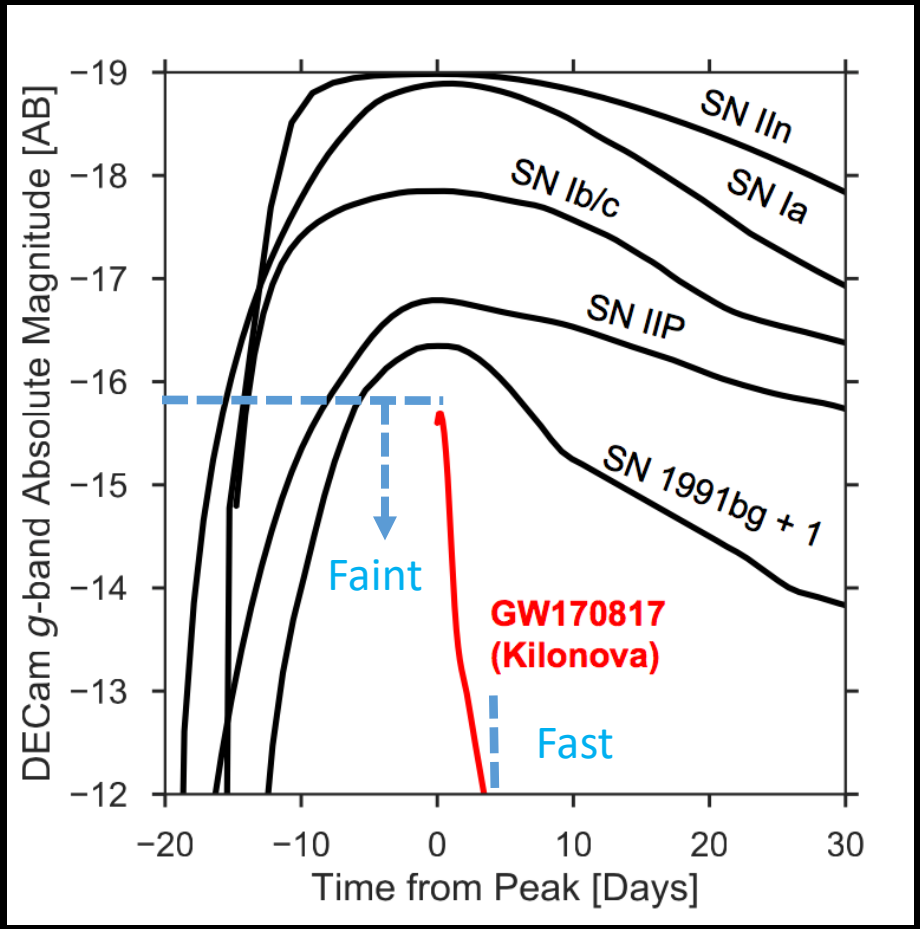
Tidally stripped ejecta
(low Y_e, high neutron content)

Post-merger ejecta
(broad range of neutron content)

Reviews e.g.: Metzger 2019, Nakar 2019, Margutti & Chornock 2021

Image credit: NASA

Kilonova: faster & fainter than supernovae

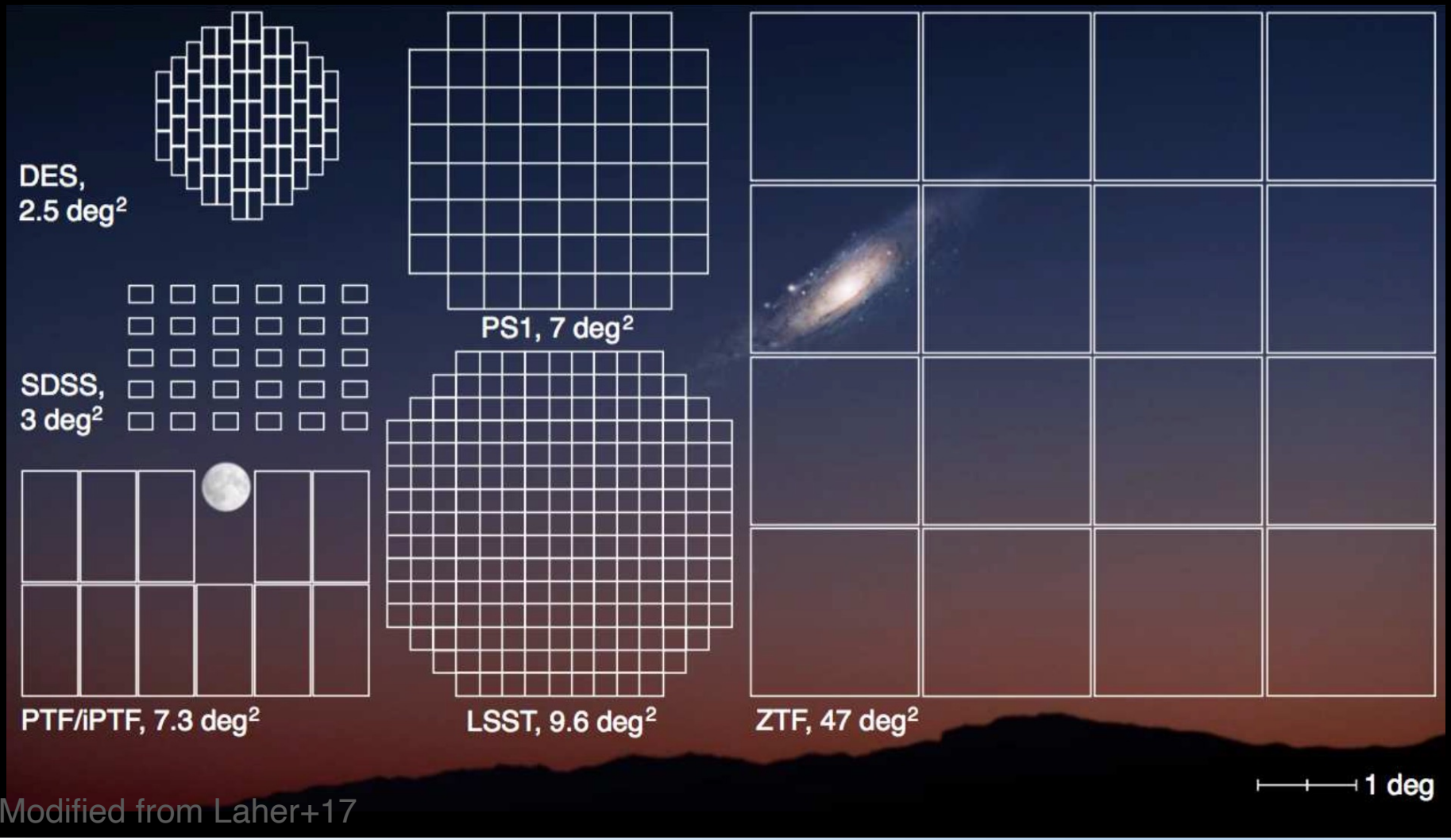


modified from Andreoni+2018

Magnitude = $-2.5 * \log_{10}(\text{flux}) + C$

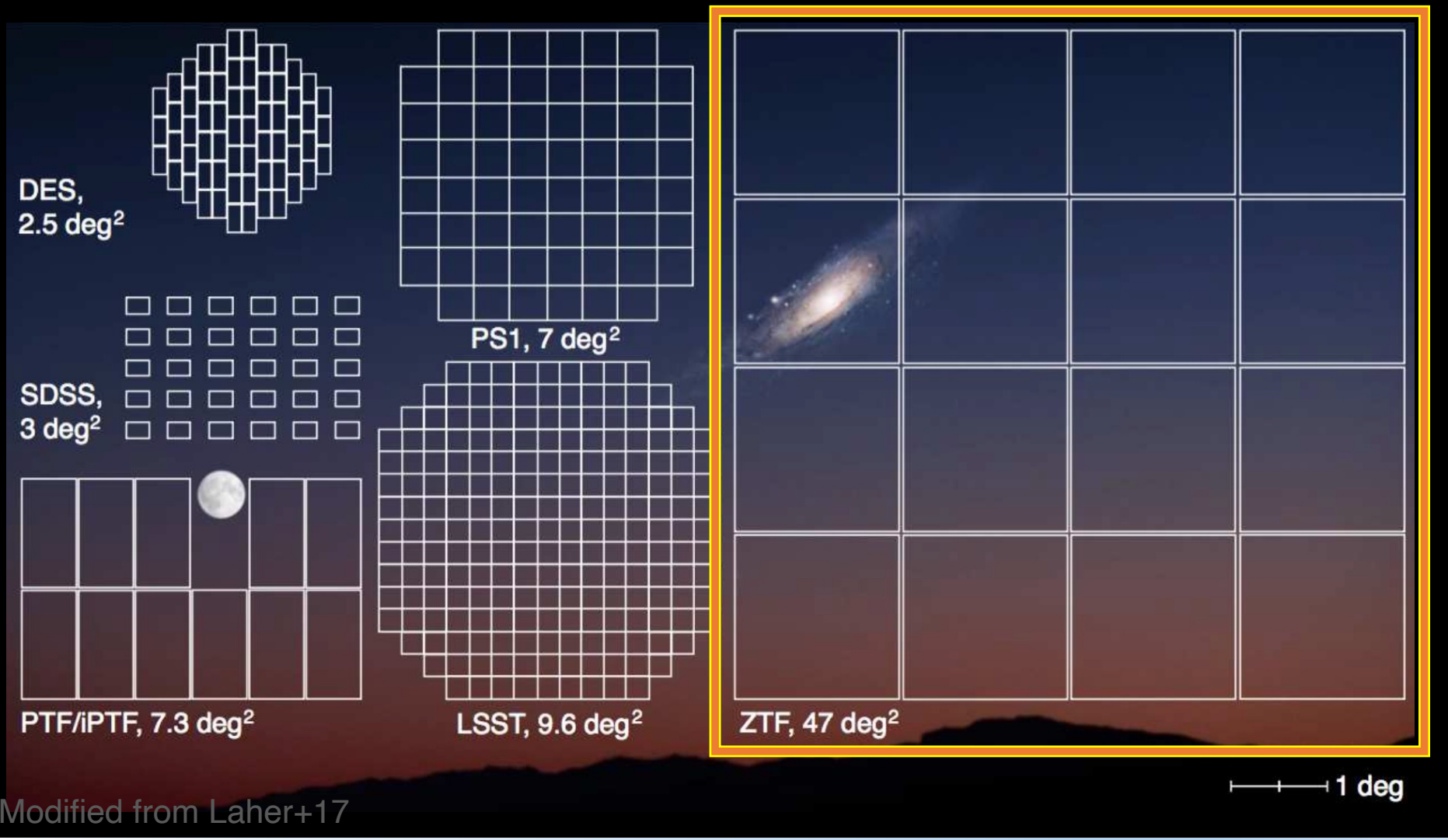
Faint + Fast = hard to catch!

Zwicky Transient Facility



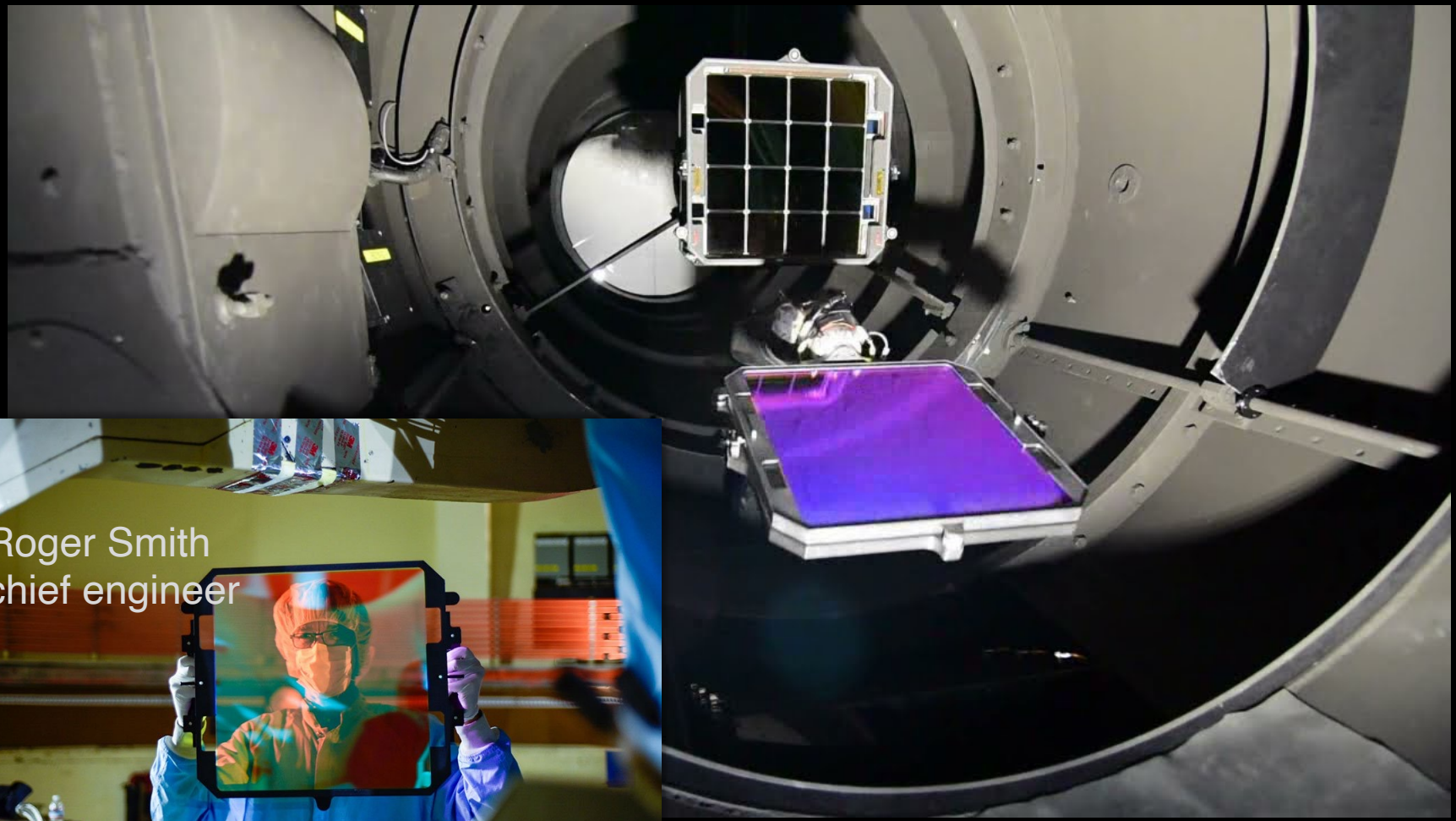
Modified from Laher+17

Zwicky Transient Facility



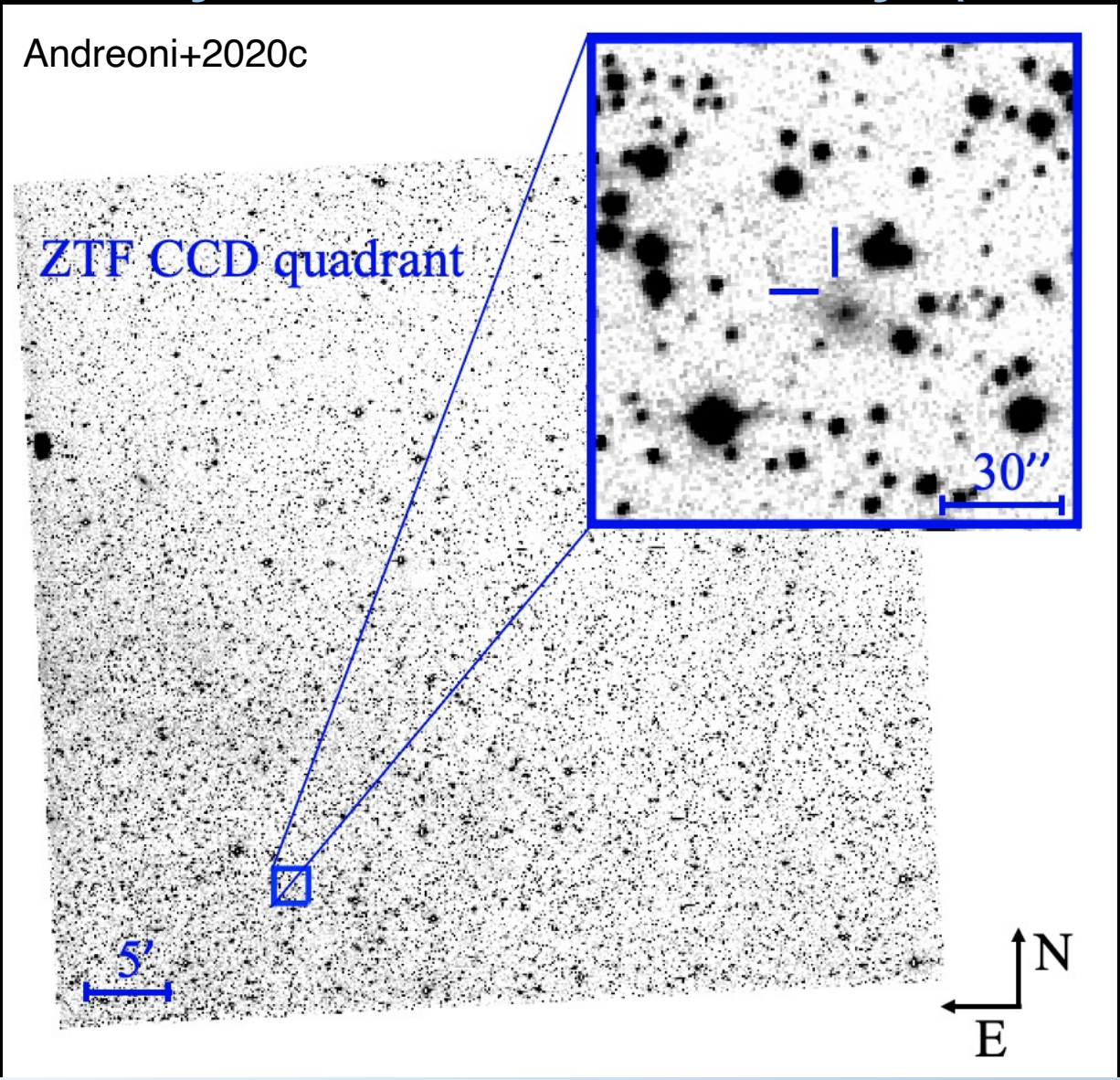
Modified from Laher+17

Zwicky Transient Facility



48-inch Samuel Oschin telescope at Palomar

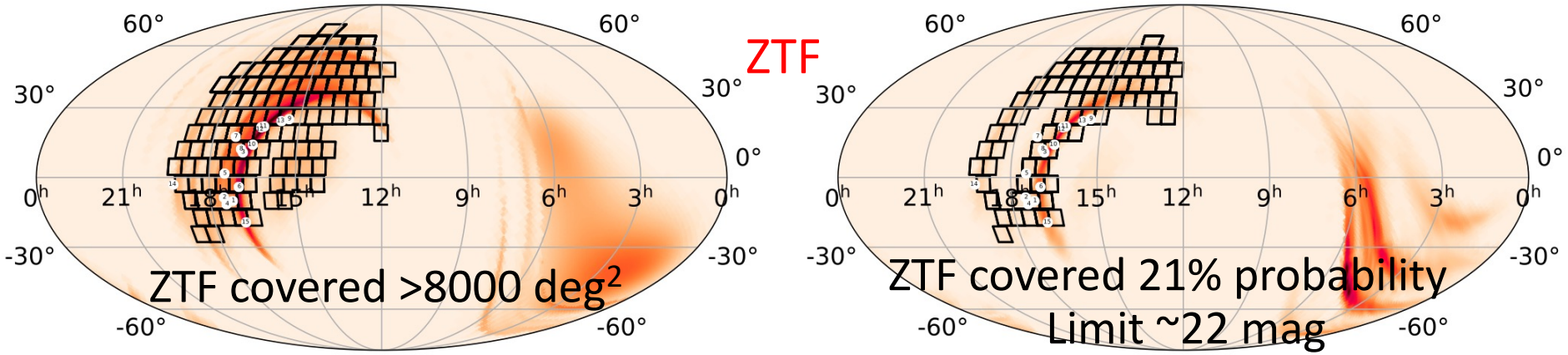
Zwicky Transient Facility (ZTF)



ZTF follow-up of the NS-NS merger GW190425

BAYESTAR

LaLInference



15 promising candidates

None was a kilonova

Coughlin, …, IA et al. (2019), ApJL, 885, 1, L19

ZTF follow-up of the NS-NS merger GW190425

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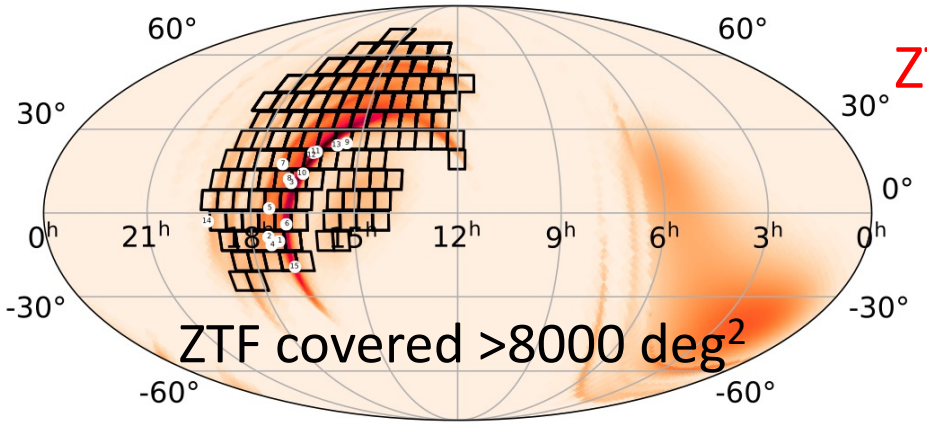
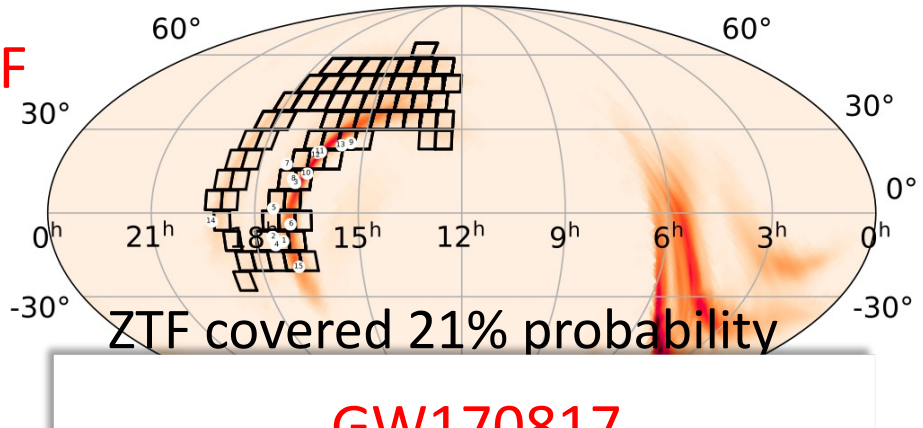


ZTF



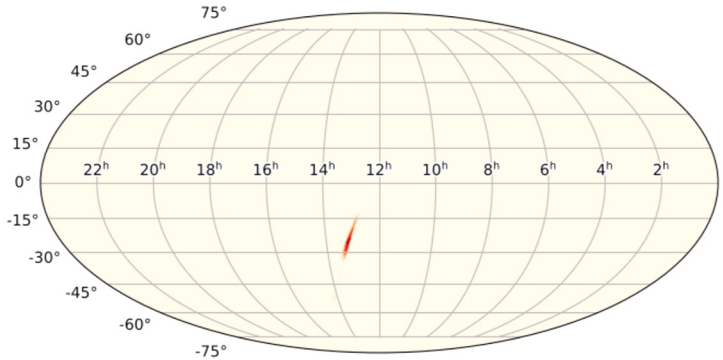
ZTF covered >8000 deg^2

ZTF covered 21% probability

15 promising candidates

None was a kilonova

GW170817



Coughlin, …, IA et al. (2019), ApJL, 885, 1, L19

ZTF follow-up of 13 NS mergers during O3

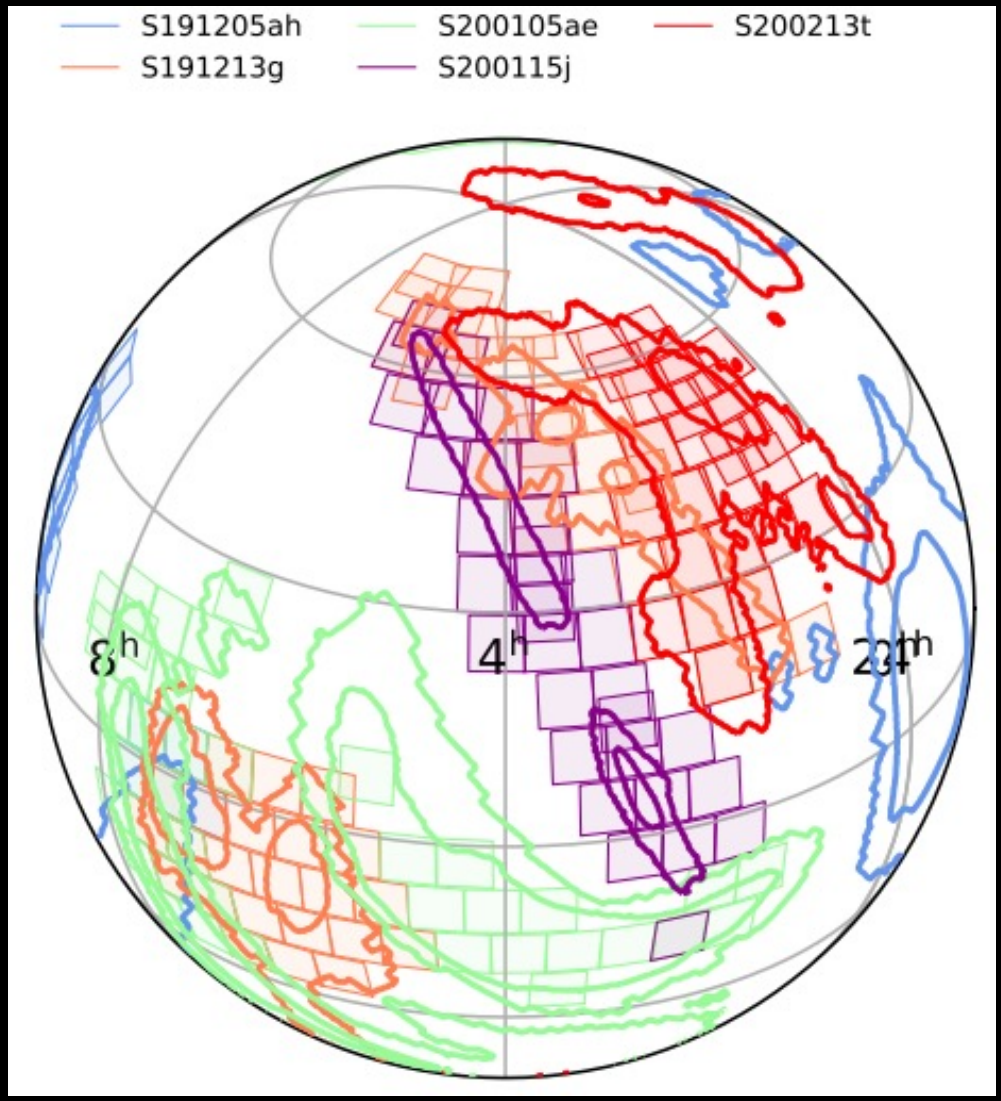
For ZTF follow-up of neutron star mergers in O3 please see:

- Second binary NS merger follow-up
  Coughlin et al. (2019),
  ApJL, 885, 1, L19

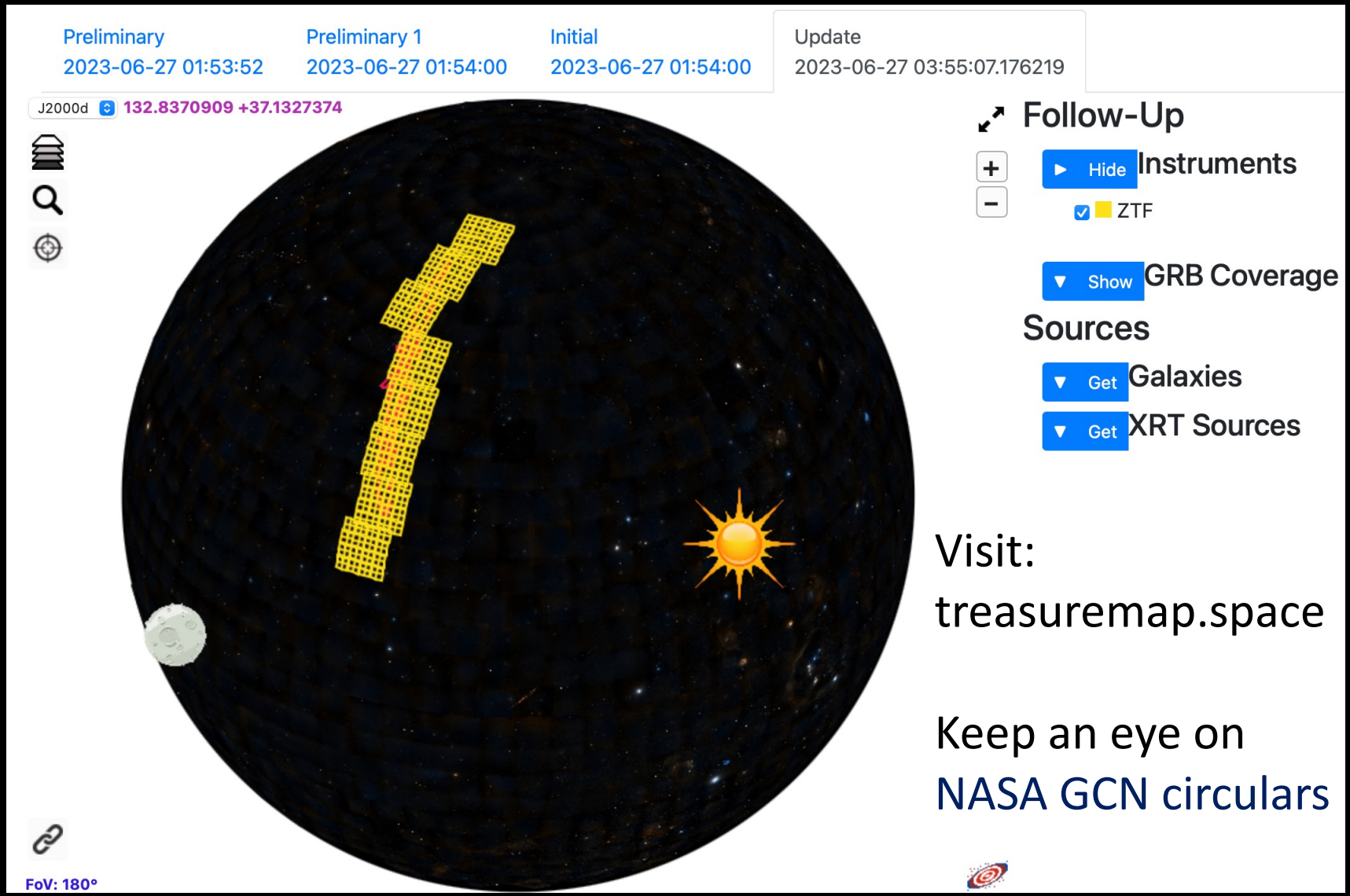
- Constraints on NS-BH merger
  Anand & Coughlin et al. (2021),
  Nature Astronomy, 5, 46

- Kilonova luminosity function
  Kasliwal et al. (2020),
  ApJ, 905, 2,145

Modified from Laher+17



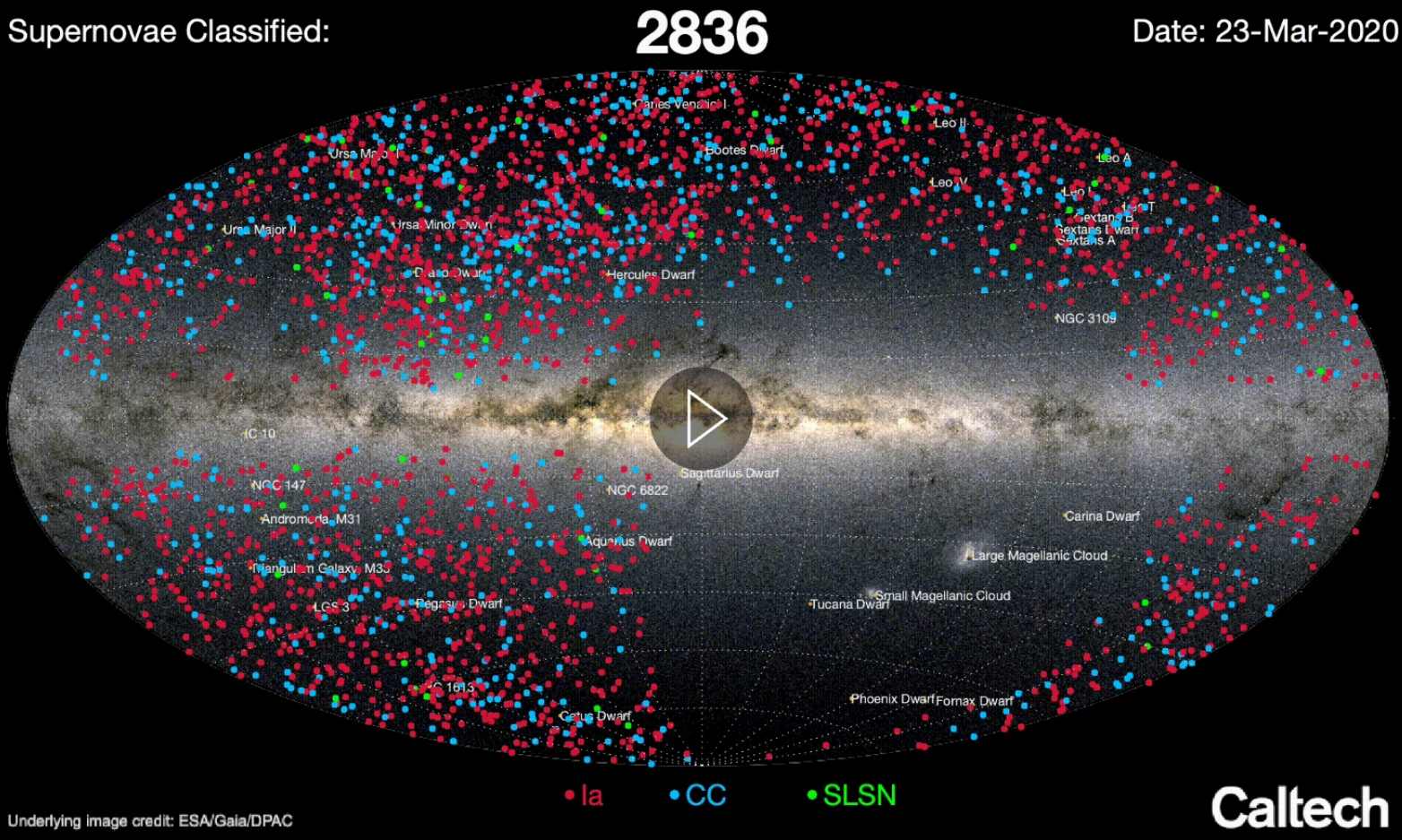
ZTF follow-up of GW events during O4



Visit:
treasuremap.space

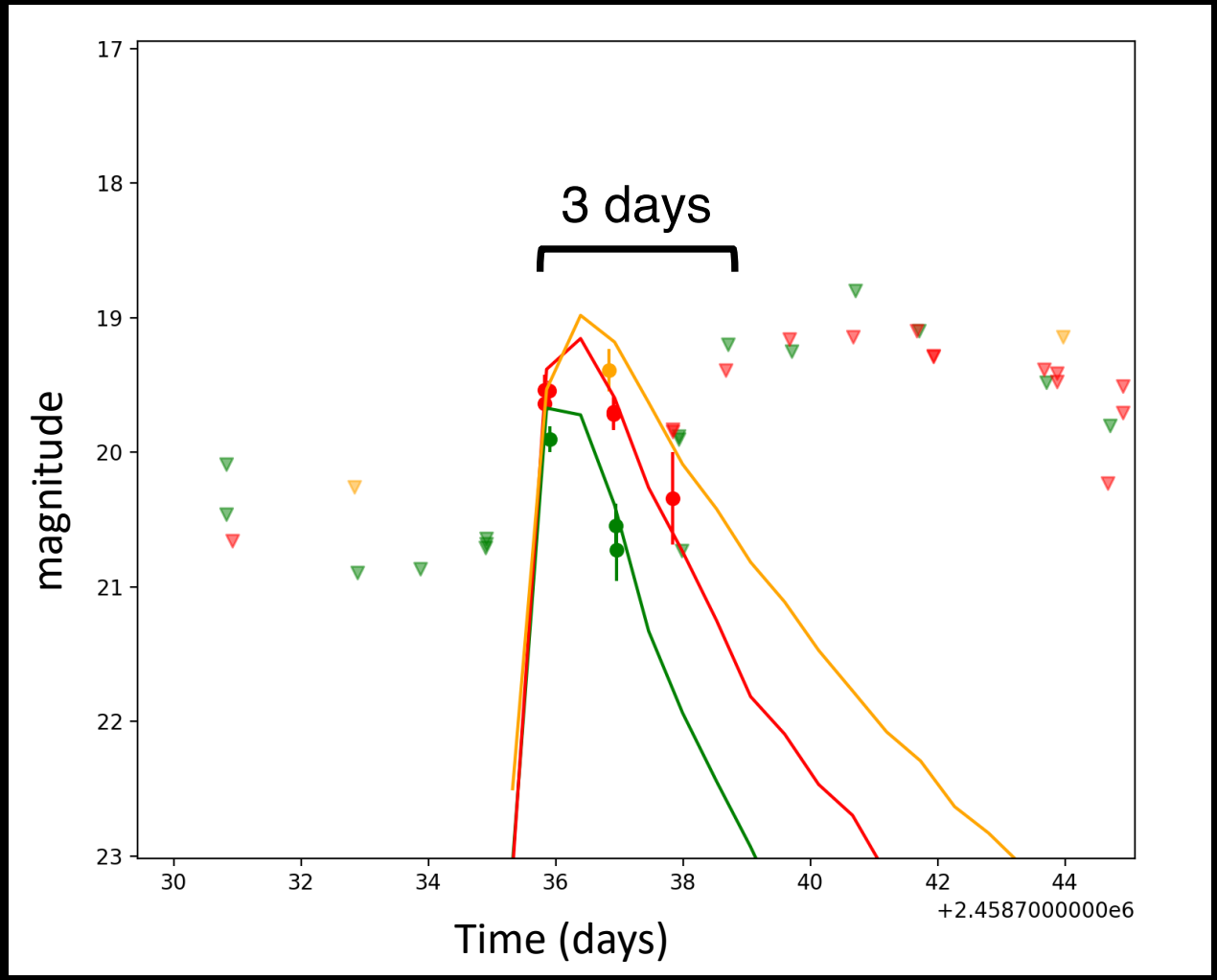
Keep an eye on
NASA GCN circulars

Un-triggered ZTF transient searches



DR 19: 51 million images, 787 billion source detections

Are there Kilonovae in ZTF data?



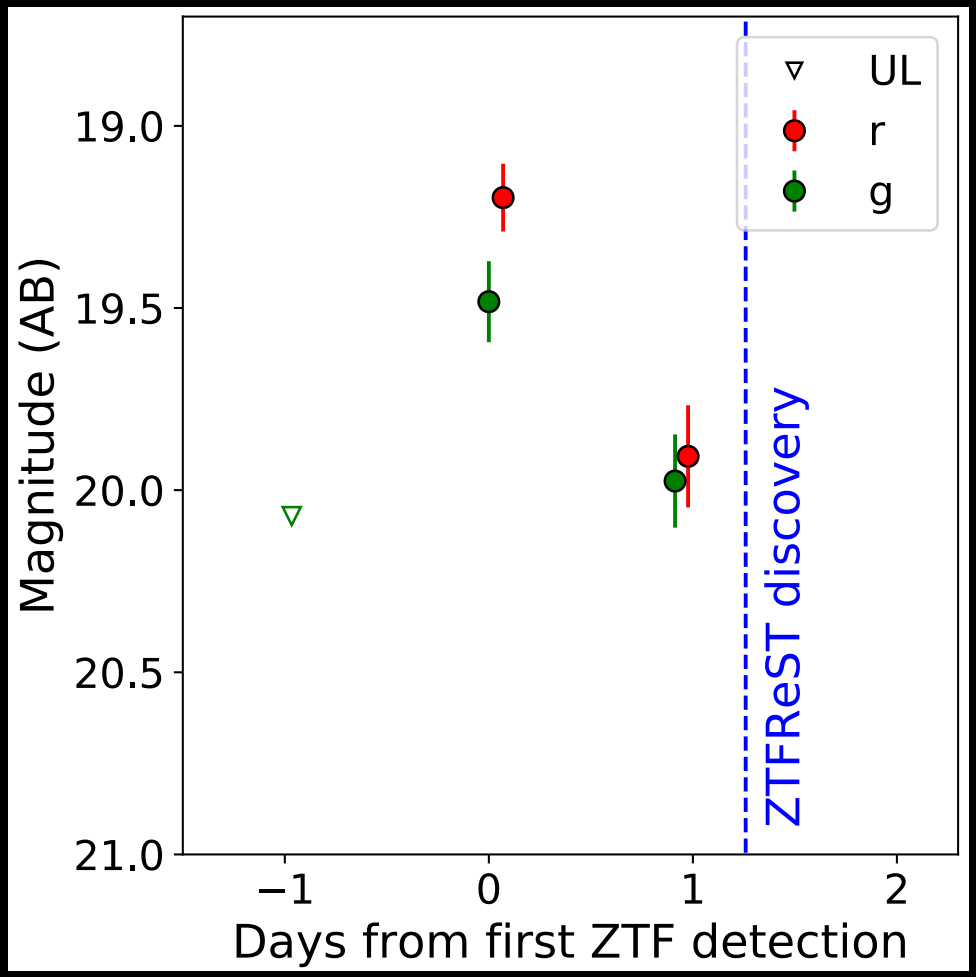
Simulated distant kilonova in ZTF data (plot by: Sagués-Carracedo @OKC)

ZTF Realtime Searching and Triggering

growth-astro/ztfrest

Michael Coughlin

Andreoni & Coughlin et al. (2021), ApJ, 918, 2, 63



Near real-time implementation of the search methods used in Andreoni et al. (2020d)

Supernova shock cooling

~ a dozen

Serendipitous GRB afterglows

- 5 with GRB association (long)
- 5 confirmed, un-triggered afterglows w/o GRB association

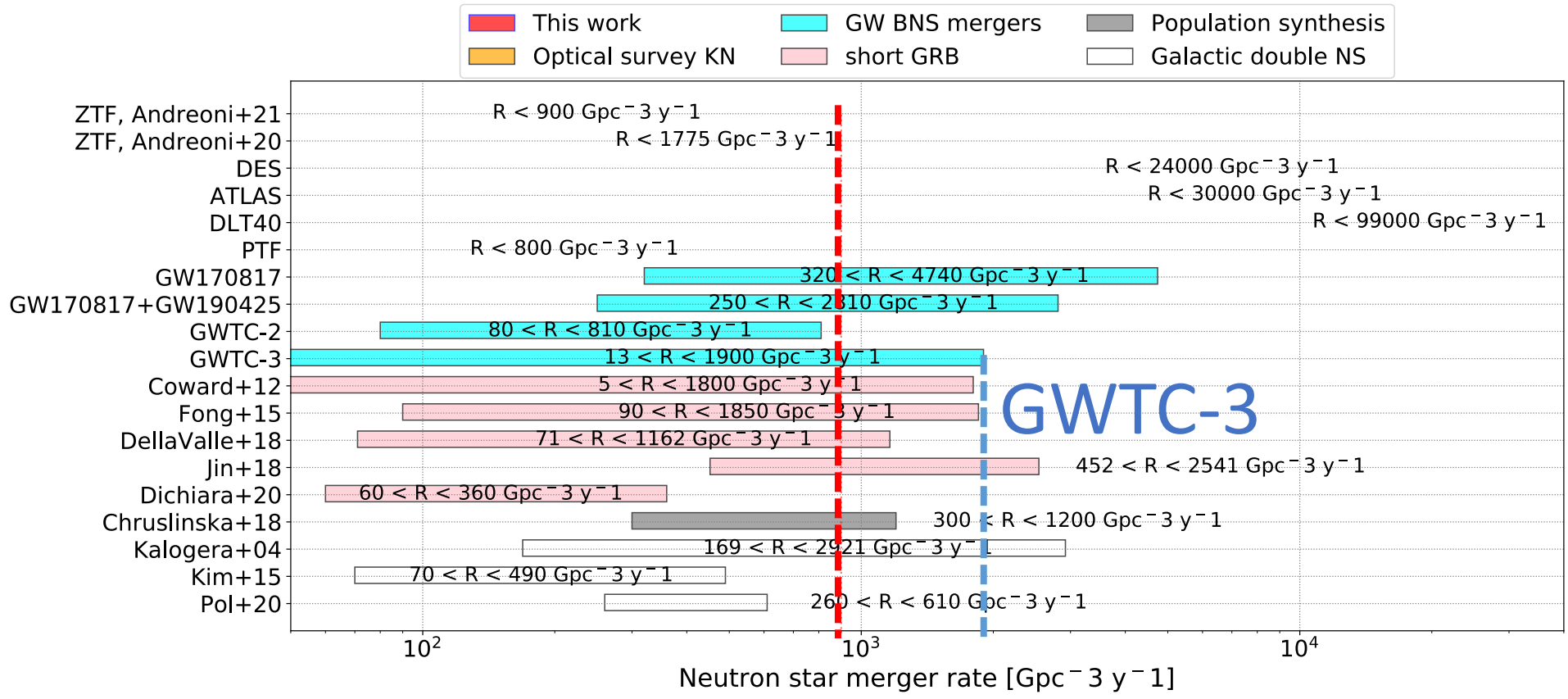
see also Ho+2020,2021,2022; Andreoni+2020d

Kilonovae

Still waiting…

Constraints on Kilonova and neutron star merger rates

Constraints on Kilonova and neutron star merger rates

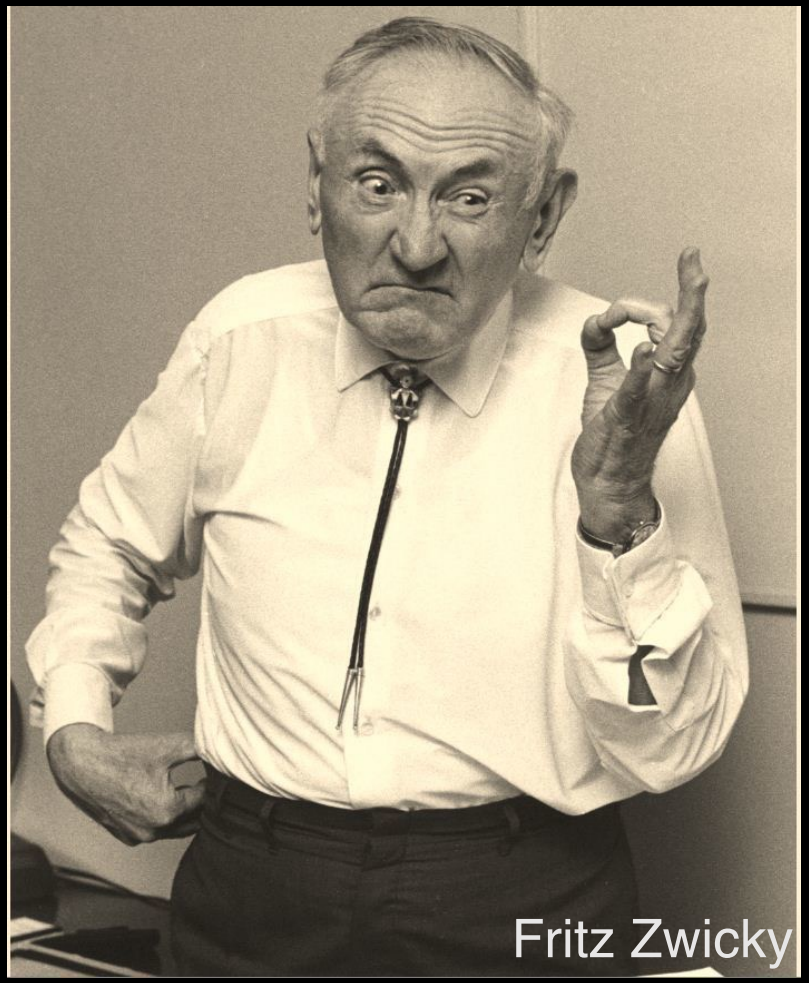


Andreoni & Coughlin et al. (2021), ApJ, 918, 2, 63

Model grid in Andreoni et al. (2020d), ApJ, 904, 2, 155

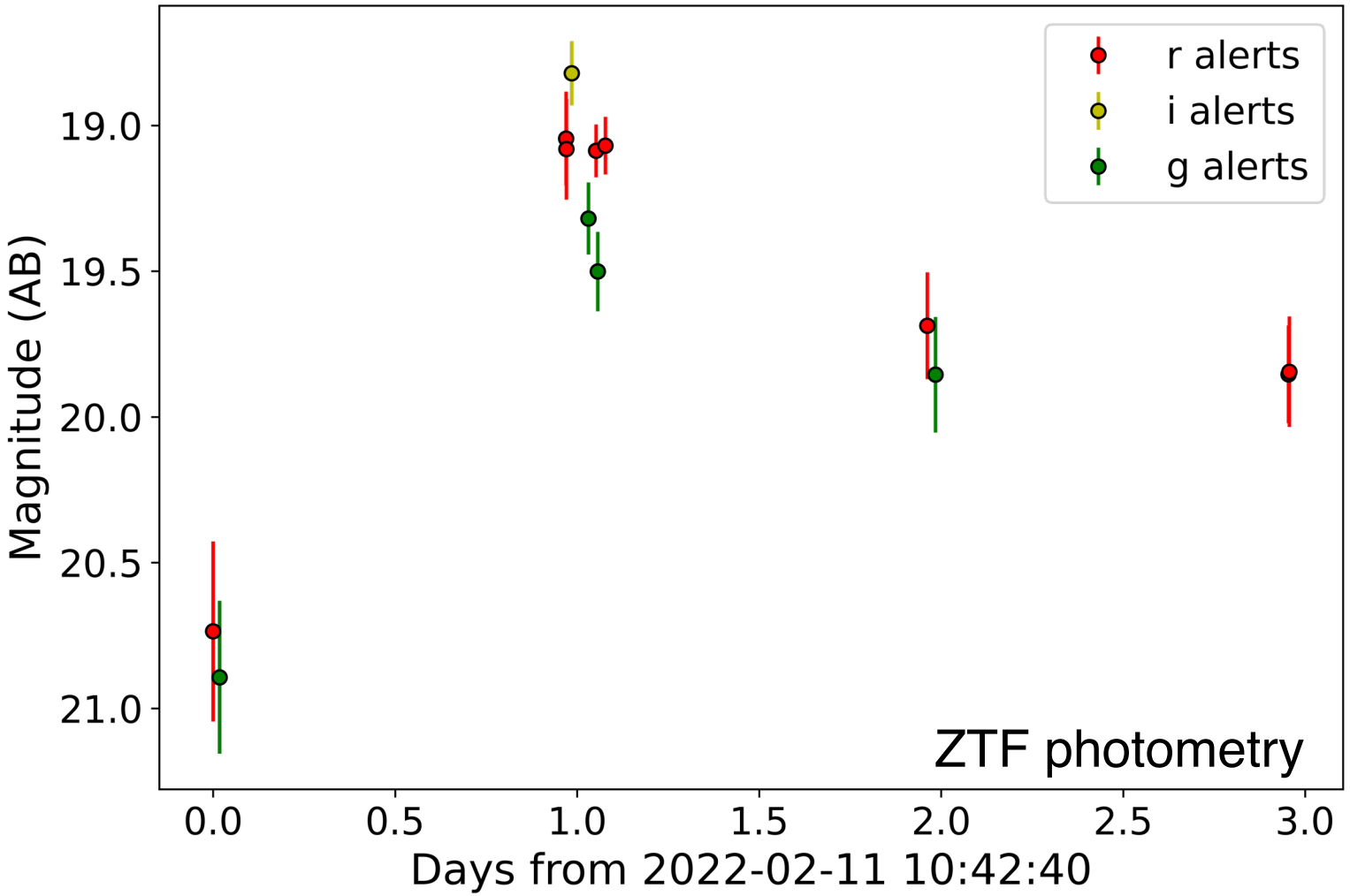
ZTF constrained the rate of GW170817-like kilonovae to be $R < 900$ Gpc^{-3} y^{-1}

Ready for the unexpected

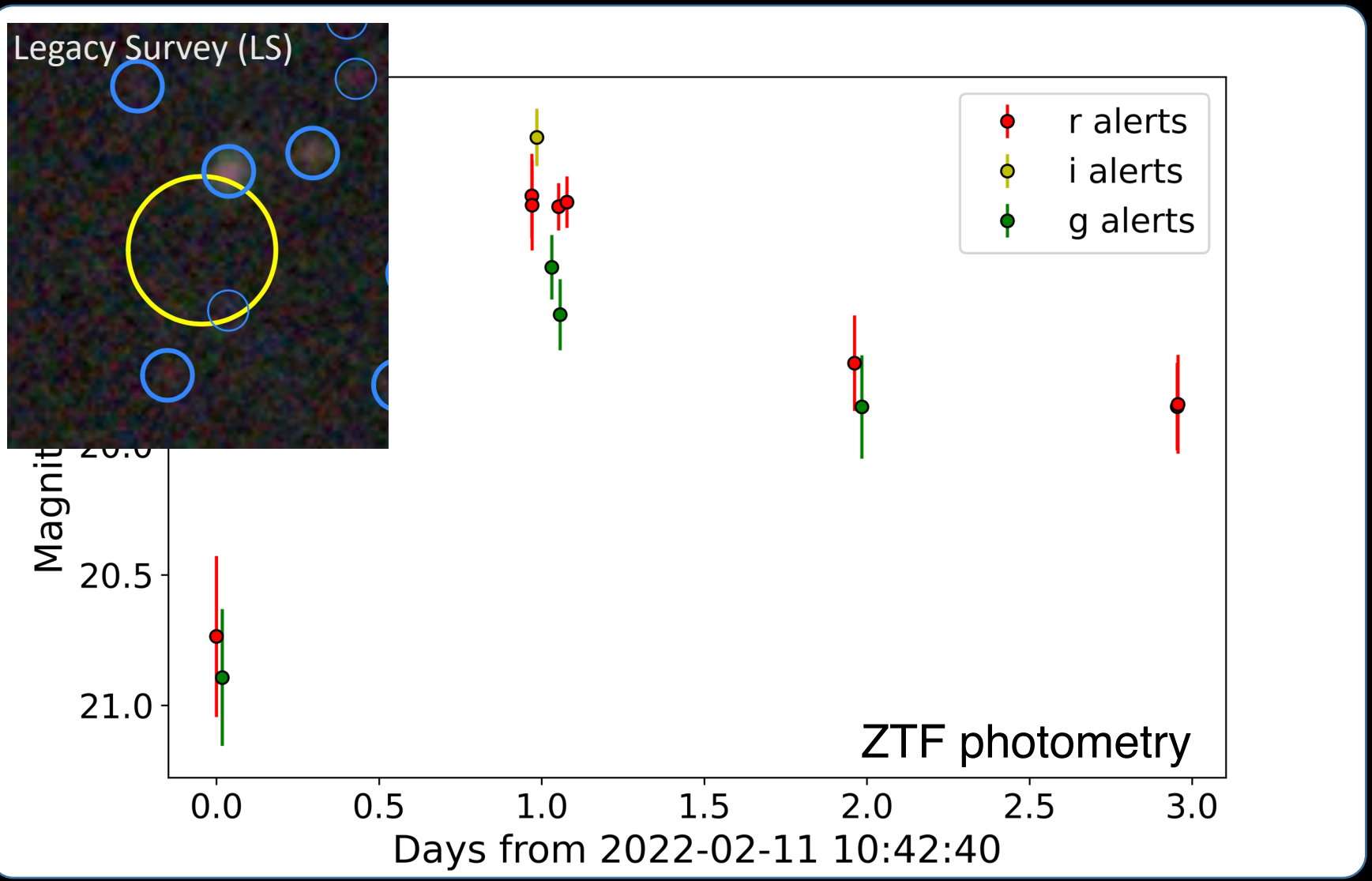


Andreoni & Coughlin et al. (2022), Nature, 612, 7940

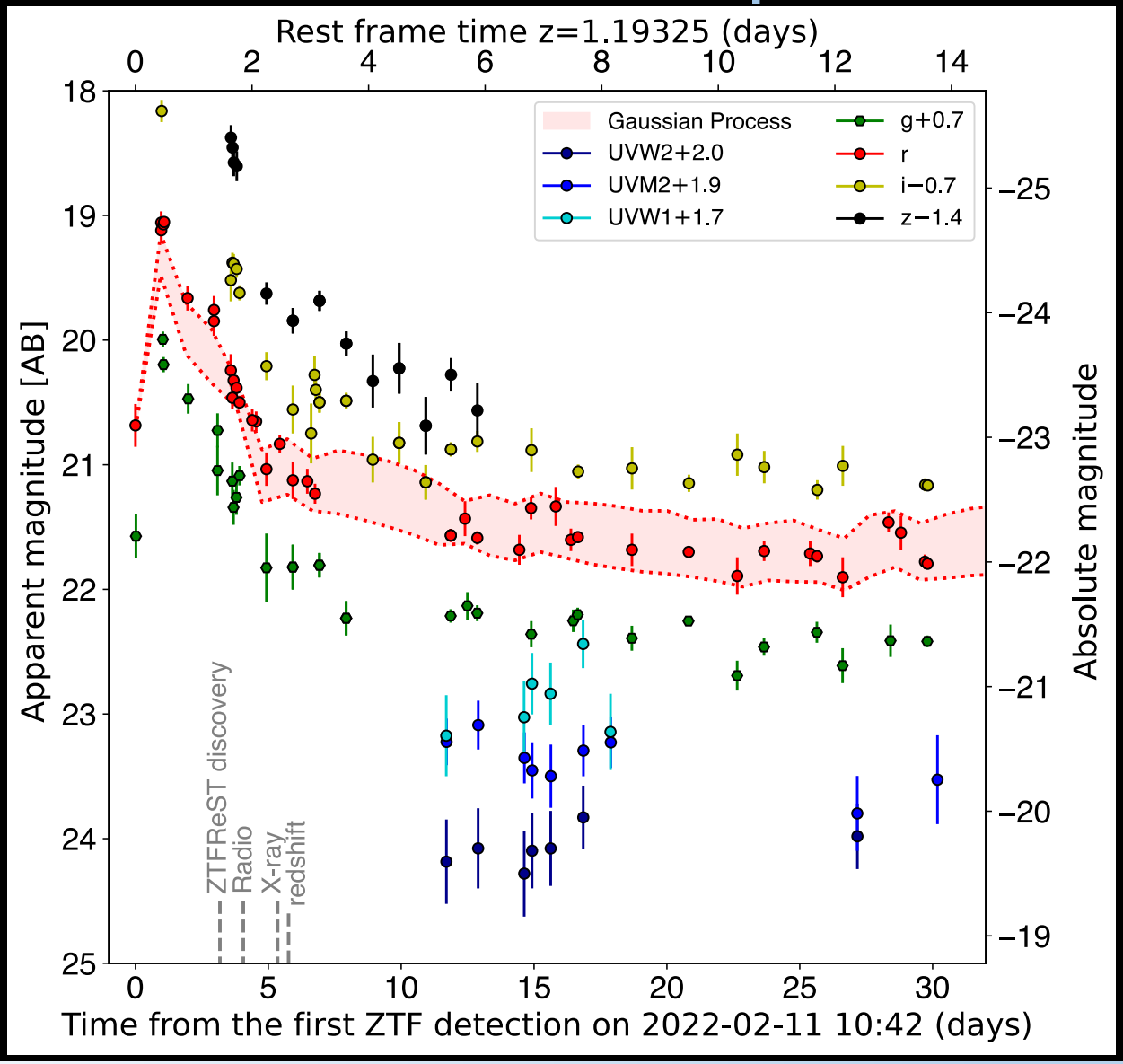
AT2022cmc: Discovery



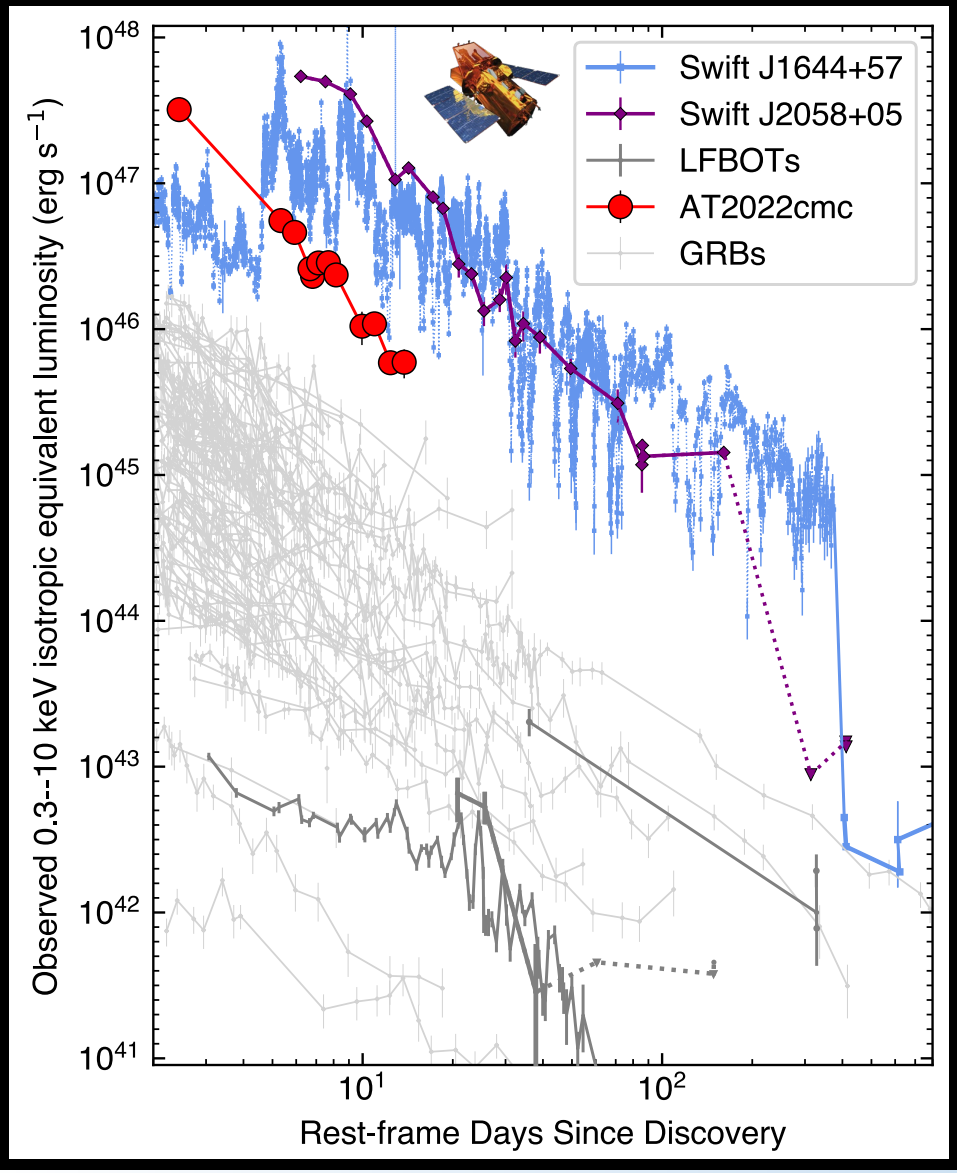
AT2022cmc: Discovery

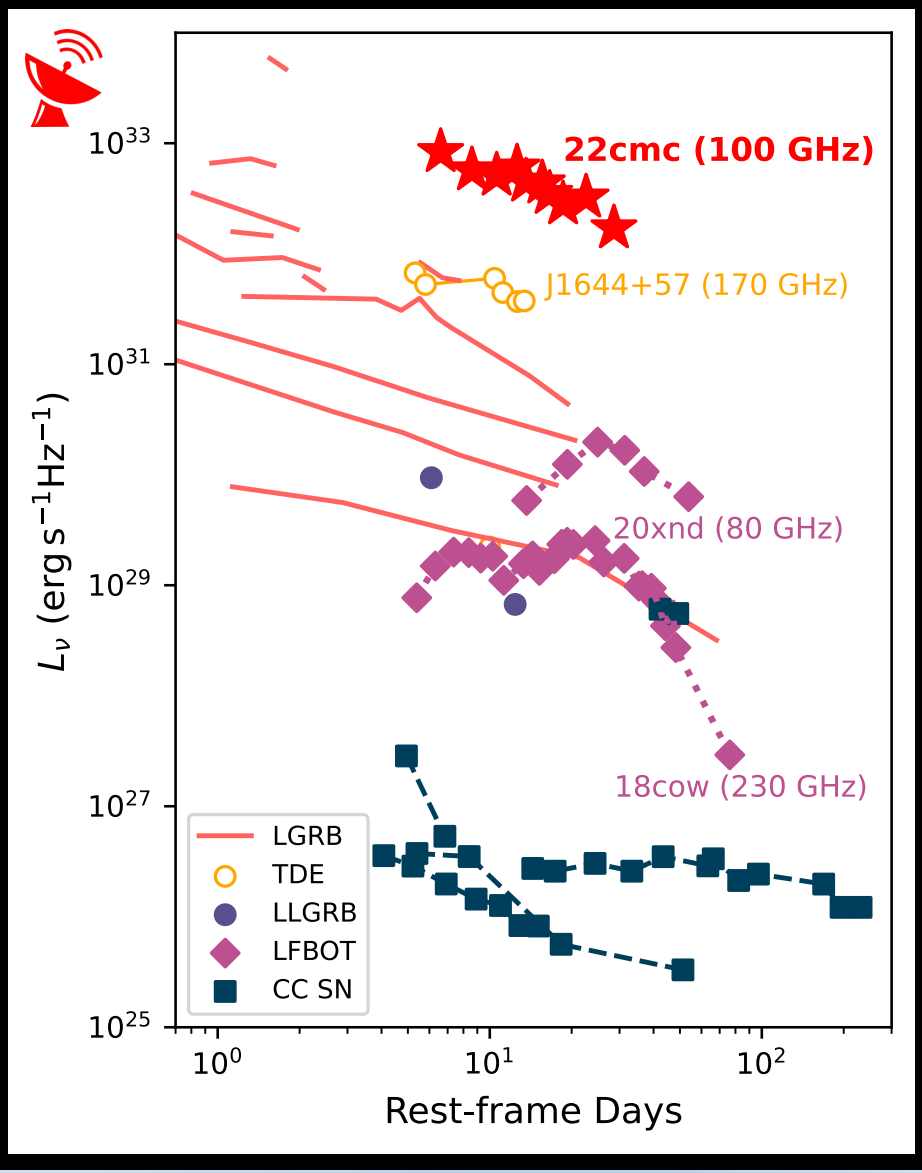


AT2022cmc: UV/Optical/nIR

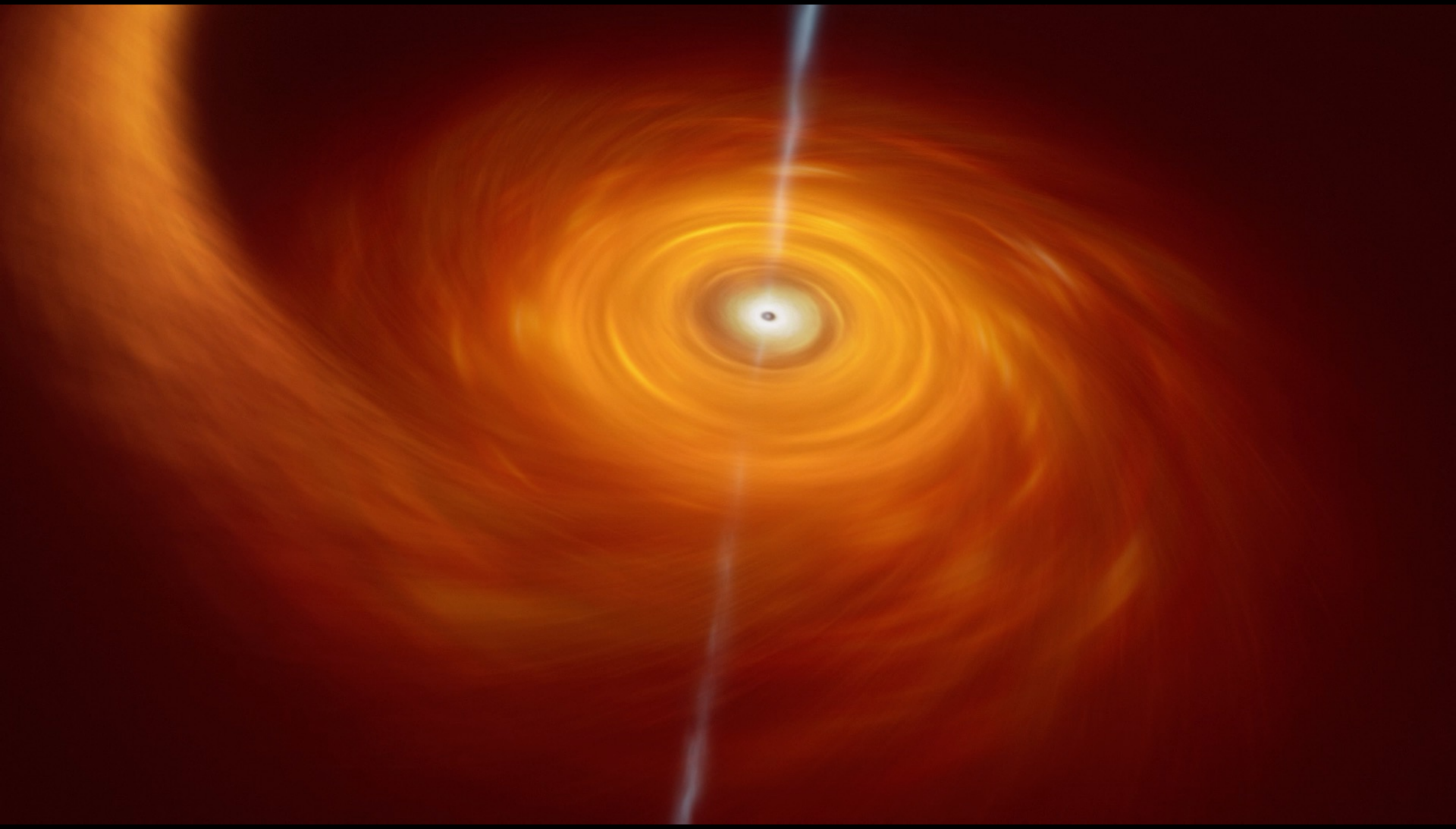


AT2022cmc: X-rays and radio/mm



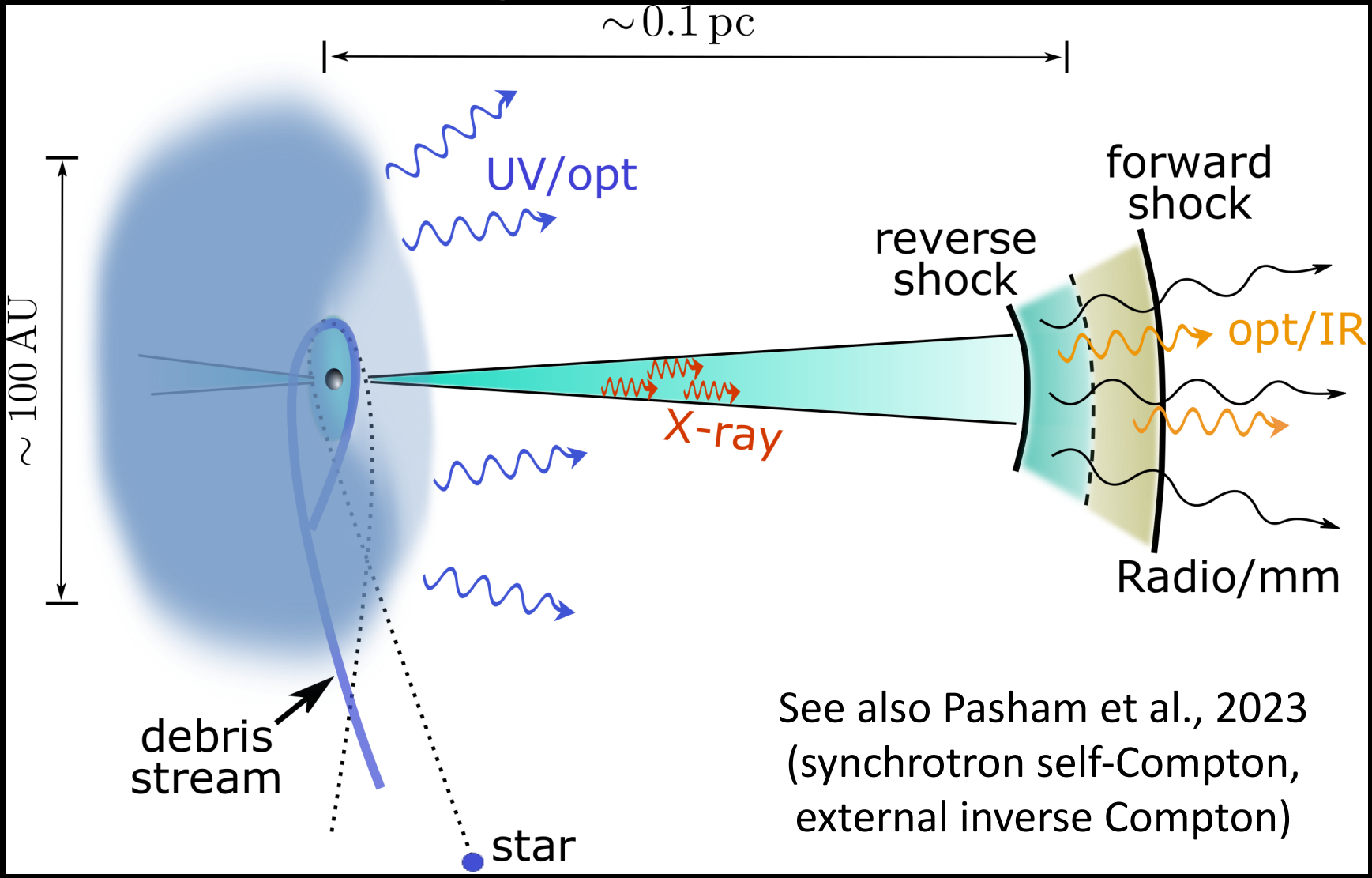


Jetted Tidal Disruption Events



Credit: ESO/M.Kornmesser

AT2022cmc: a jetted tidal disruption event



AT2022cmc: The furthest TDE ever observed - the first jetted TDE identified by an optical survey

Summary/Take-away

Many open questions remain about kilonovae and neutron star mergers

Systematic ZTF follow-up of LIGO-Virgo-KAGRA triggers science (individual events, luminosity function) even without a positive counterpart detection – waiting for a kilonova in O4!

Systematic searches in ZTF constrained the rate of GW170817-like kilonovae to be $R < 900\ \mathrm{Gpc^{-3}\ y^{-1}}$, which can tell us something about the neutron star merger rate

Un-triggered searches for fast transients unveiled the first optically-discovered jetted TDE, which ZTF confirmed to be ~1% of the TDE population