The Sub-solar Mass GW Event S250818k: Optimizing Electromagnetic Counterpart Searches with TROVE

Charlie Kilpatrick
on behalf of the TROVE collaboration

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See Franz+2025, arXiv:2510.17104

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CENTER FOR INTERDISCIPLINARY EXPLORATION AND RESEARCH IN ASTROPHYSICS

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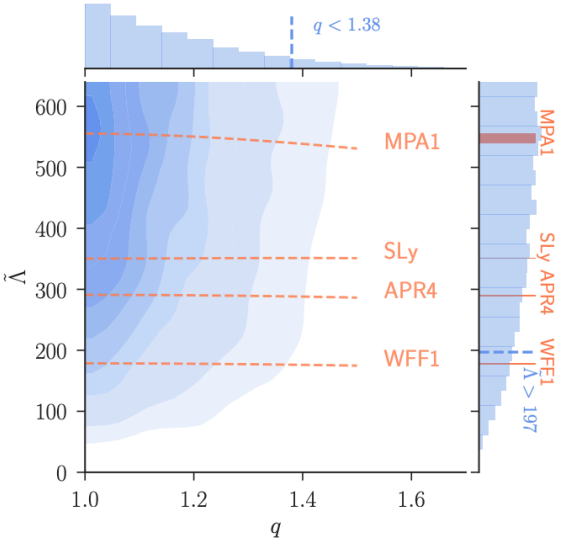
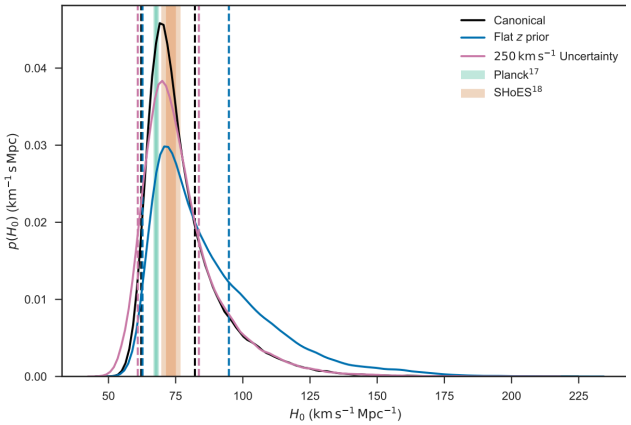
EM Localization Opens Unique MMA Science



The Nuclear Equation of State

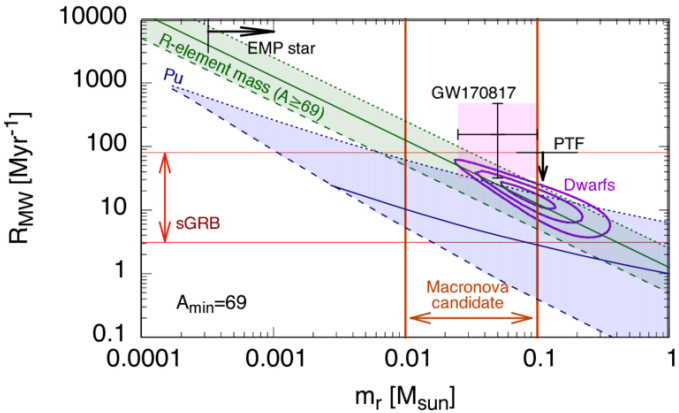
Coughlin+2018



Precise GW Cosmology

$H_0 = 70^{+12}_{-8}$ km s^{-1} Mpc^{-1}

Abbott+2017



Heavy Element Nucleosynthesis

Hotokezaka+2018

The Localization Process is ***HARD!***

How do we rapidly search for and acknowledge when we've found the electromagnetic counterpart to a GW event?

- This has significant implications for search strategy, telescope allocation, and the feasibility of finding a statistical sample of EM counterparts
  - LSST search strategy, follow-up with NASA/NSF facilities (JWST, HST, VLA, Chandra) all predicated on counterpart being "identified"

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e.g., from Andreoni, Margutti, et al. on LSST search strategy (Rubin ToO 2024):

> If the counterpart is not identified by Night 2, we will repeat observations on a fourth night (Night 3). We will assume that 4 epochs are required.

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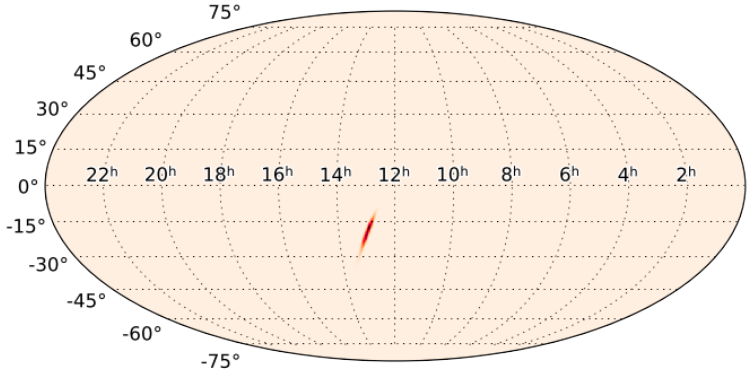
- This is challenging for technical reasons (volume of data to analyze, crossmatching to many ancillary catalogs) and because GW/EM counterparts are so poorly understood

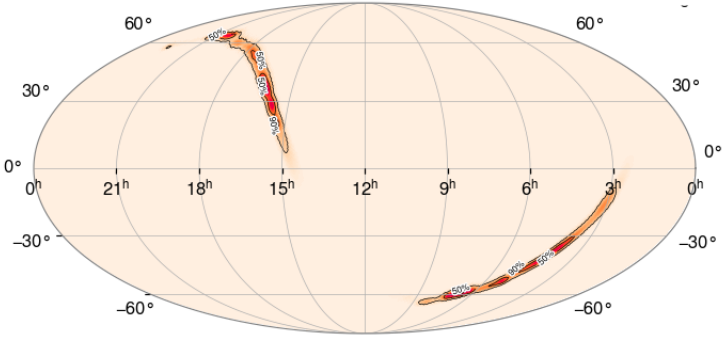
The Localization Process is ***HARD!***

2D Localization: Multiple detector events - especially with Virgo - helps a lot



GW170817: ~30 deg²

Credit: LIGO/Virgo; Abbott+2017

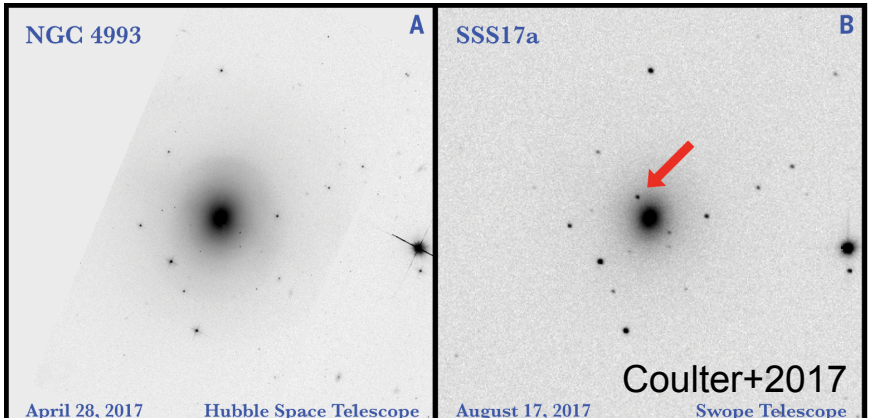


S250818k: ~800 deg²

Credit: LVK; GraceDB

The Localization Process is ***HARD!***

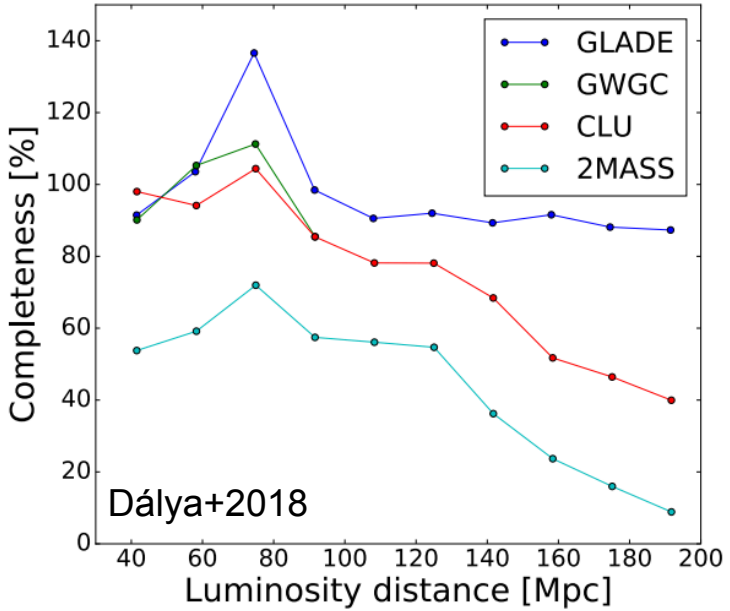
Distance Criterion: Are galaxies at the GW-predicted luminosity distance?



Dreyer 1888

No.	G. C.	J. H.	W. H.	Other Observers.	Right Ascension, 1860·0.	Annual Precession, 1880.	North Polar Distance, 1860·0.	Annual Precession, 1880.	
4992	3427	1541	...	...	13 2 6	2·99	77 37·0	19·3	vF, S, lE, 2 S st s
4993	3428	...	III 766	...	13 2 12	3·23	112 38·4	19·3	vF, vS
4994	3429	3471	...	...	13 2 16	3·22	111 48·1	19·3	pF, cS, R, slbM, am st

GW170817 occurred at 40 Mpc in a volume of Universe where virtually all $M_* > 10^9\ M_\odot$ galaxies are known



Completeness high but begin declines at >160 Mpc (S250818k at ~250 Mpc)

The Localization Process is ***HARD!***

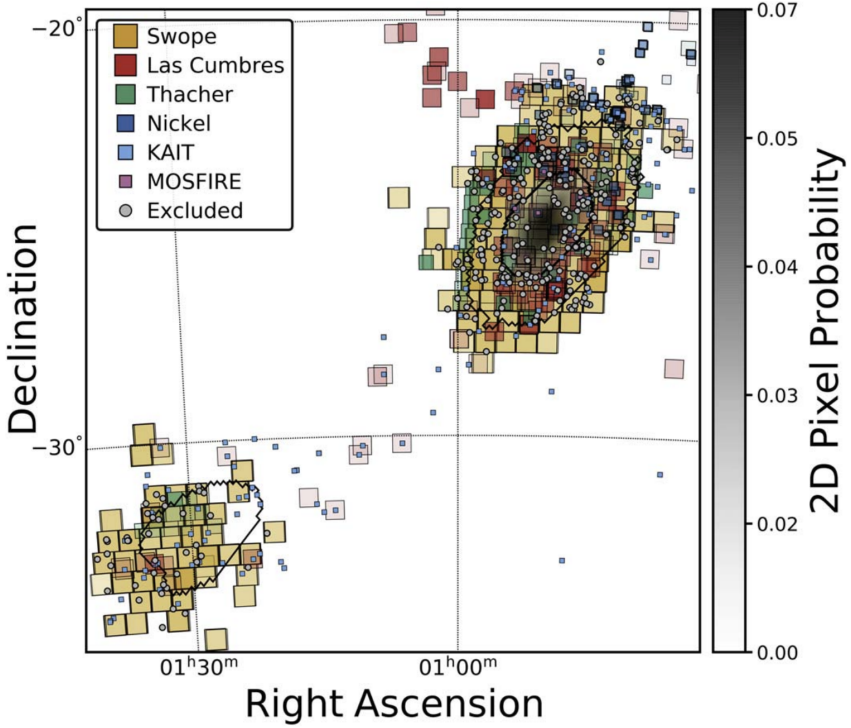
Distance Criterion: Are galaxies at the GW-predicted luminosity distance?

GW190814

189 candidates (e.g. Kilpatrick+2021)

~50% ruled out using distance criteria

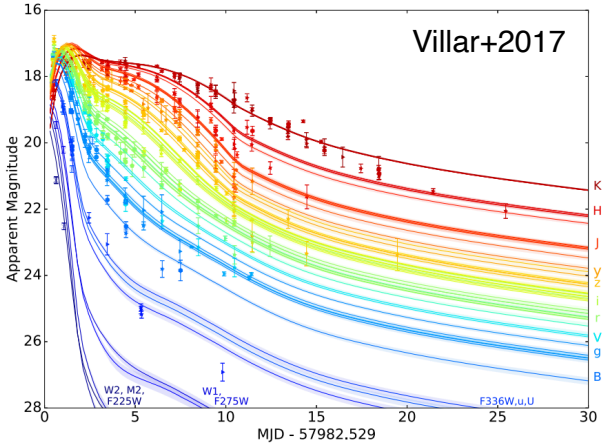
~2/3 of O3 GW candidate counterparts ruled out using real-time information (Rastinejad+2022)



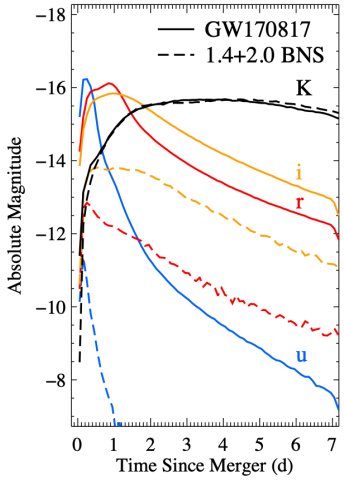
The Localization Process is ***HARD!***

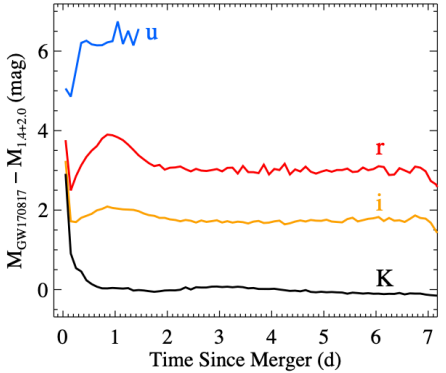
Photometric Information: What do GW counterparts look like?

- Kilonova/GRB afterglow/GW170817-like
  - Reasonable assumption if one or more components is definitely a NS, but what kind of kilonova?



GW170817 was surprisingly blue (Metzger+2014, Kasen+2015, Tanaka+2016 notwithstanding)





Foley, Coulter, Kilpatrick+2020

How much variance can there be as a function of GW-observable parameters?

The Localization Process is ***HARD!***

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- Kilonova/GRB afterglow/GW170817-like
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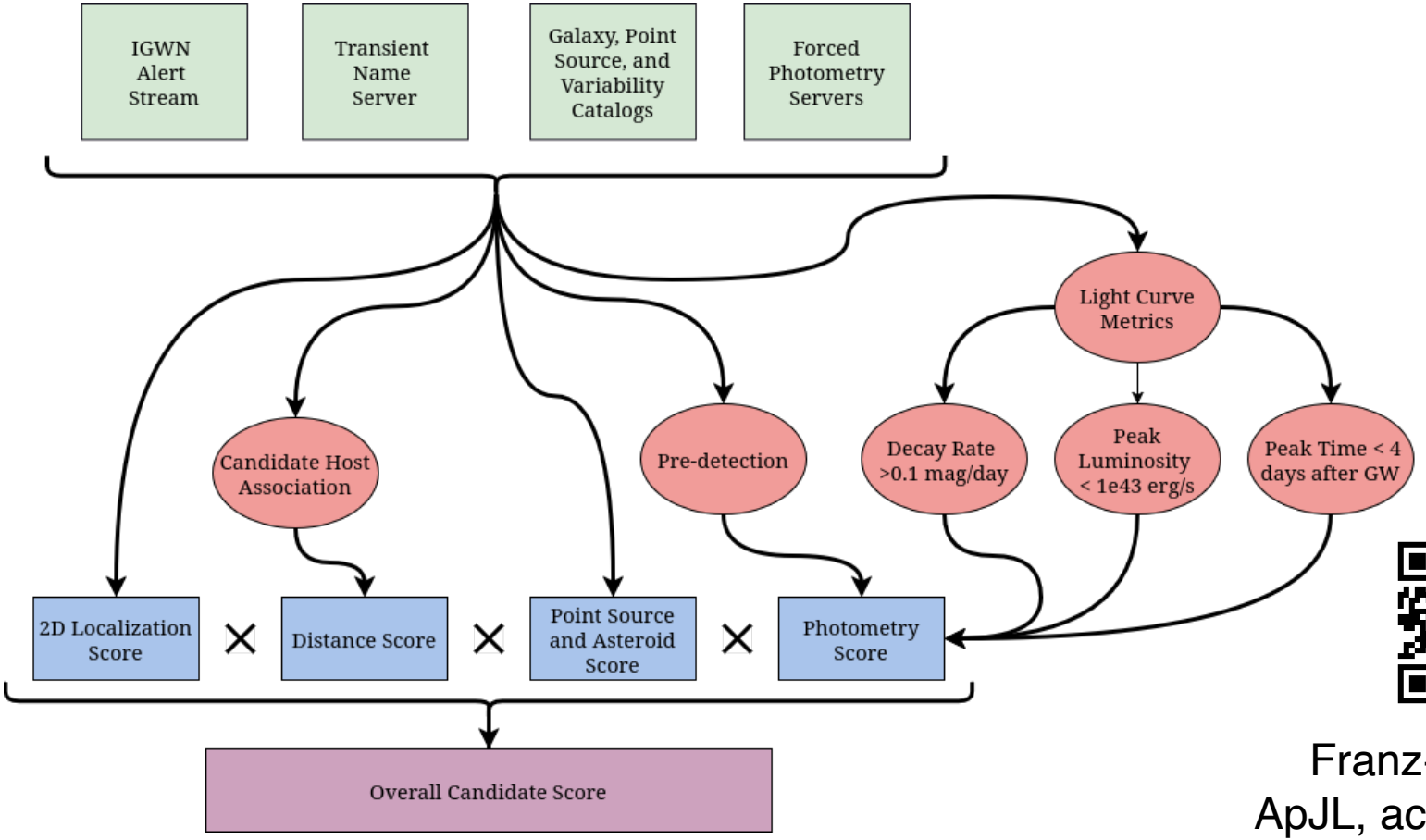
- More exotic counterparts: "superkilonova" (see Xander Hall and Brian Metzger's talks, Siegel+2022, Metzger+2024) for sub-solar mass events resembling a supernova, GRBs, FRBs, X-ray transients, radio afterglows

- Nothing? Non-detections for nearby, well-observed subsolar mass events would support existence and mergers of low-mass primordial black holes

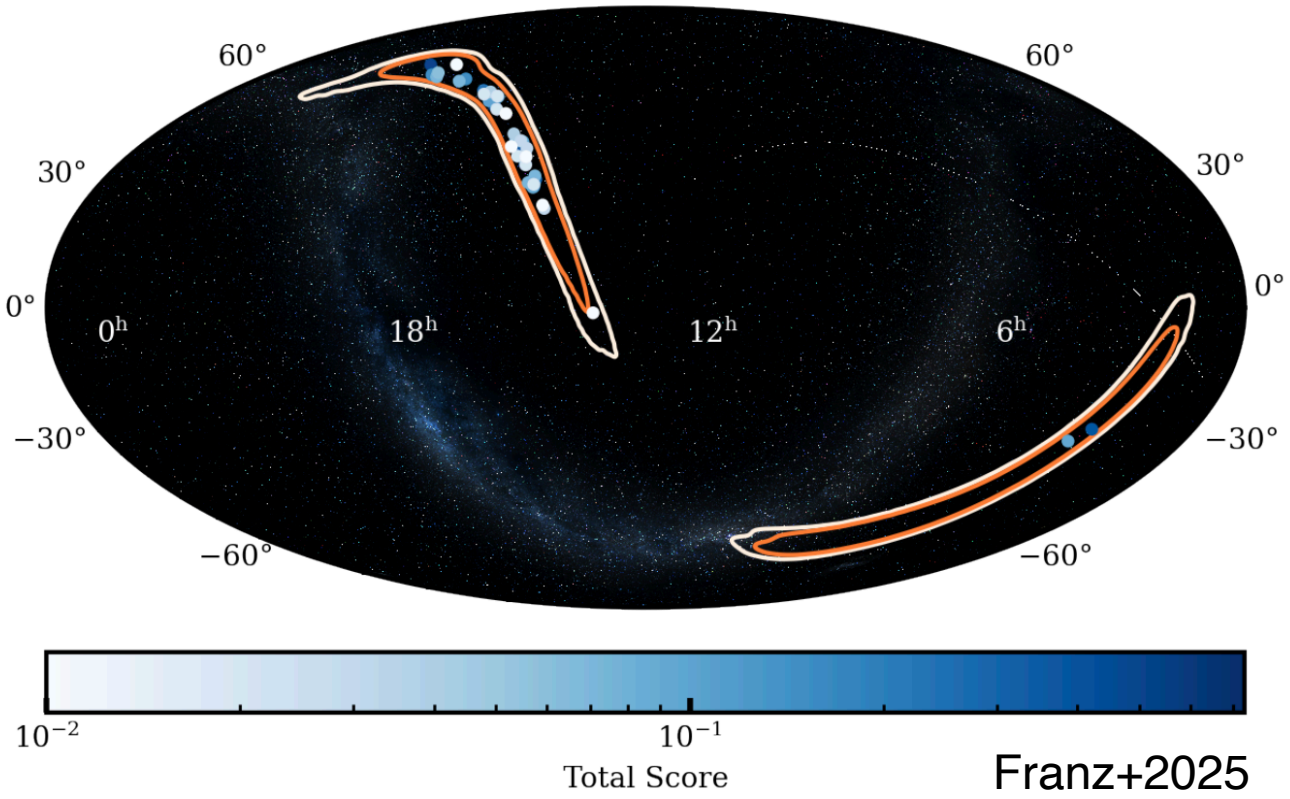
The Tool for Rapid Object Vetting and Examination (TROVE) v0.1 GW Vetting Algorithm



Franz+2025, ApJL, accepted

Application to Transients in the S250818k Localization

- 121 total candidates within the S250818k localization
- Which ones should receive follow up based on real-time information?



TROVE v0.1 Web Interface

SN2025ulz

Classify | Edit | Share | Delete | Vet

Names	SN2025ulz	
	🔗S250818k	
Coords.	15:51:54.201	+30:54:08.67
	237.975838	30.902408
Galactic	49.509535	50.630027
Ecliptic	225.504783	49.514382

Score Details

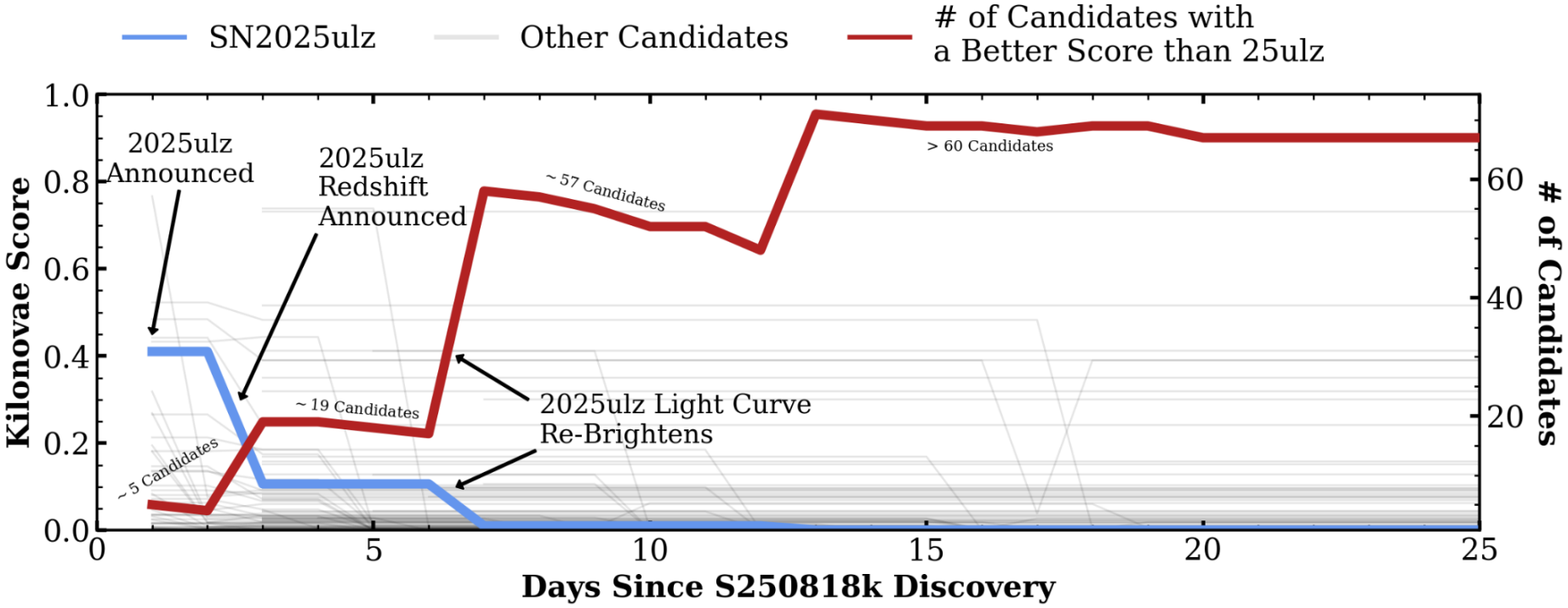
S250818k

2D Localization Score: 0.66
Point Source Score (1 or 0): 1
3D Association Score: 0.17
Maximum Luminosity: 4.89 x 10^{41} erg/s
Time of Maximum Light Curve: 26.76 days
Light Curve Slope (positive is brightening): 3.01 mag/day

▸ Host Galaxies

▾ Photometry

Application to Transients in the S250818k Localization



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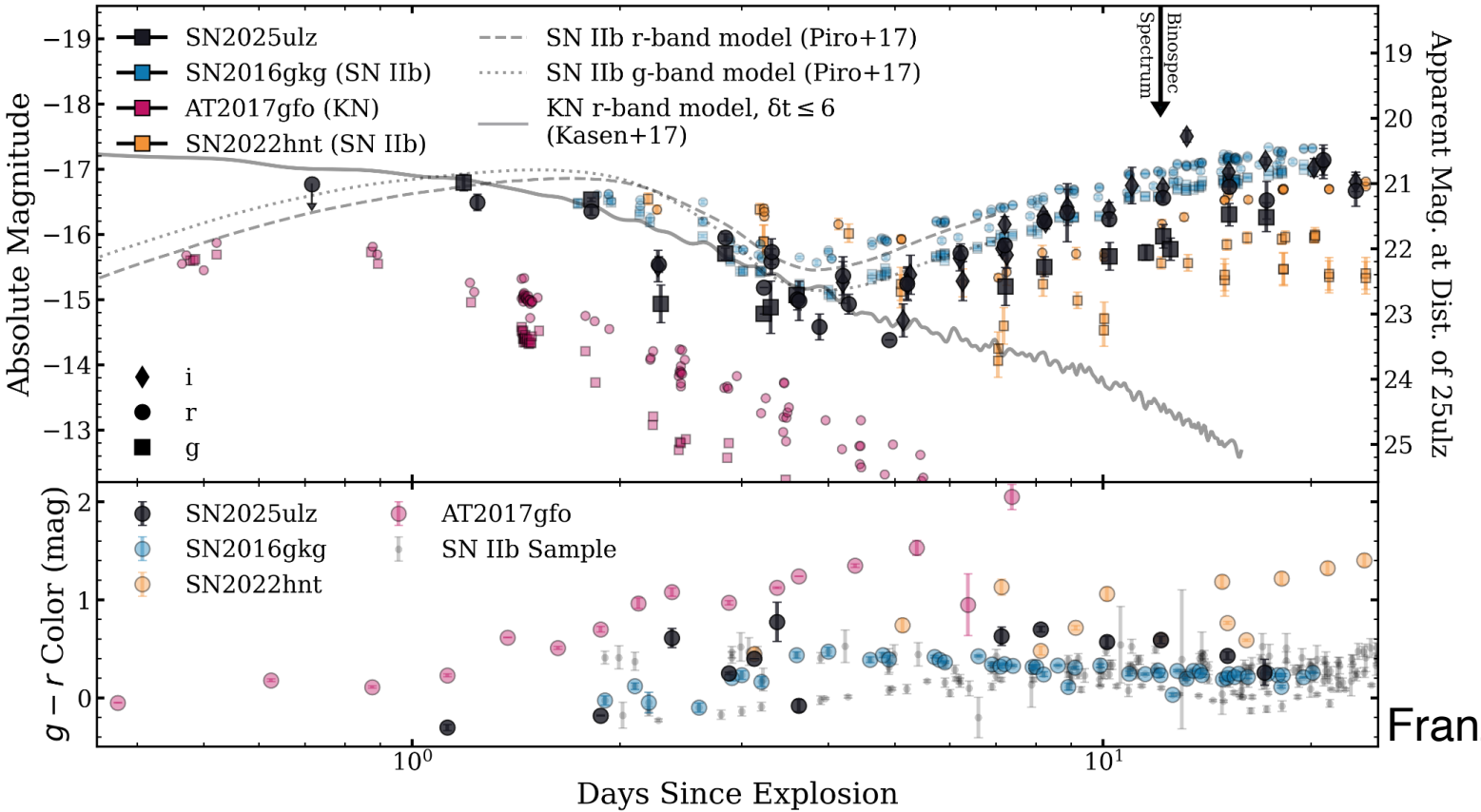
2025ulz Photometry



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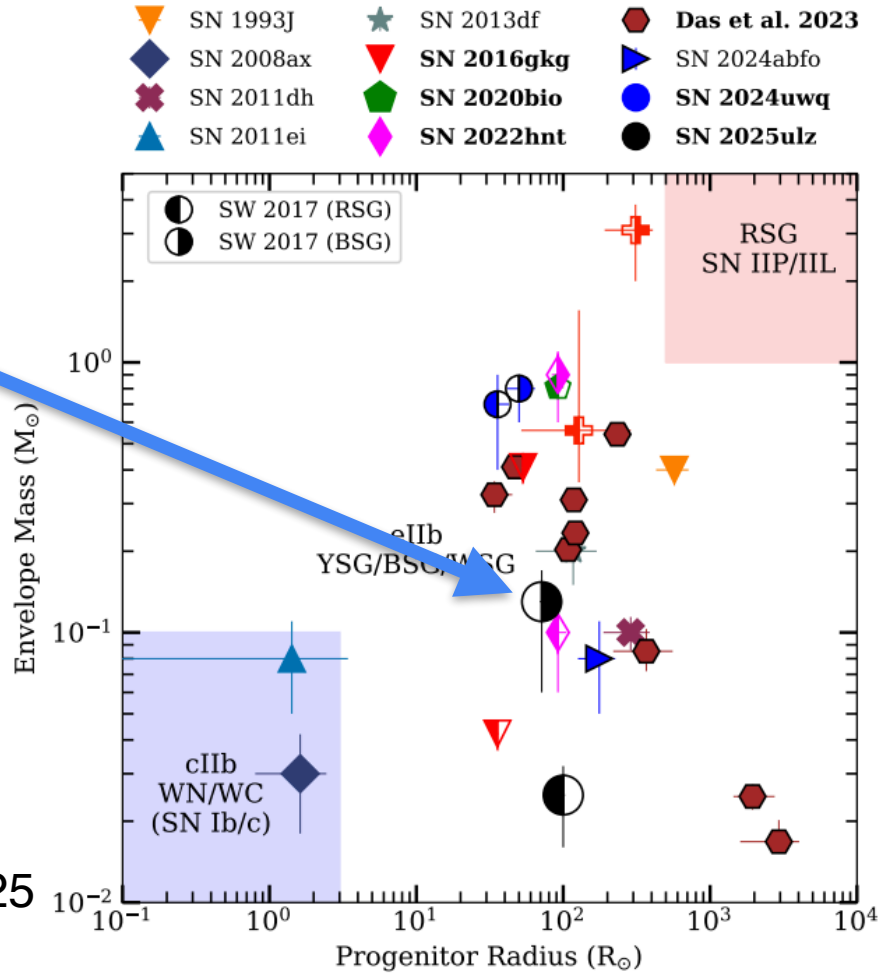
SN2025ulz early light curve assuming a H-rich envelope

The colors and brightness of SN2025ulz are consistent with the overall distribution of SN IIb observations



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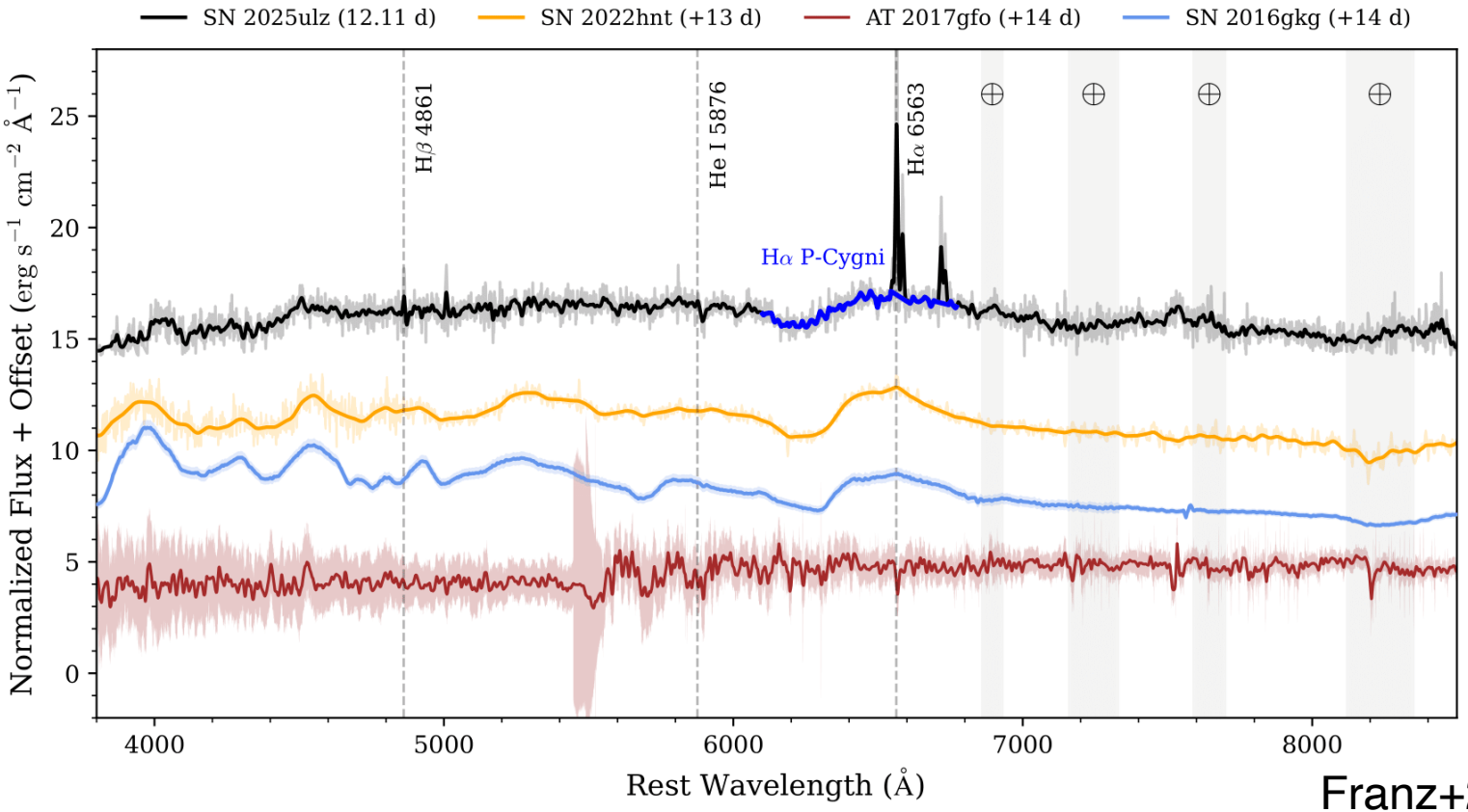
2025ulz Spectra



Franz+2025

Summary

- We need a way to rapidly converge on "identification" of bonafide EM counterparts to GW events - TROVE is one solution that will provide publicly accessible vetting for multi-messenger counterparts (neutrinos too!)

- We demonstrated that this algorithm correctly scores SN2025ulz highly at early times but this declines as more follow-up data are obtained

- Other candidates were also scored highly but did not receive as much follow up

- Expect to see TROVE v1.0 and real-time public vetting of GW counterparts before Fall 2026

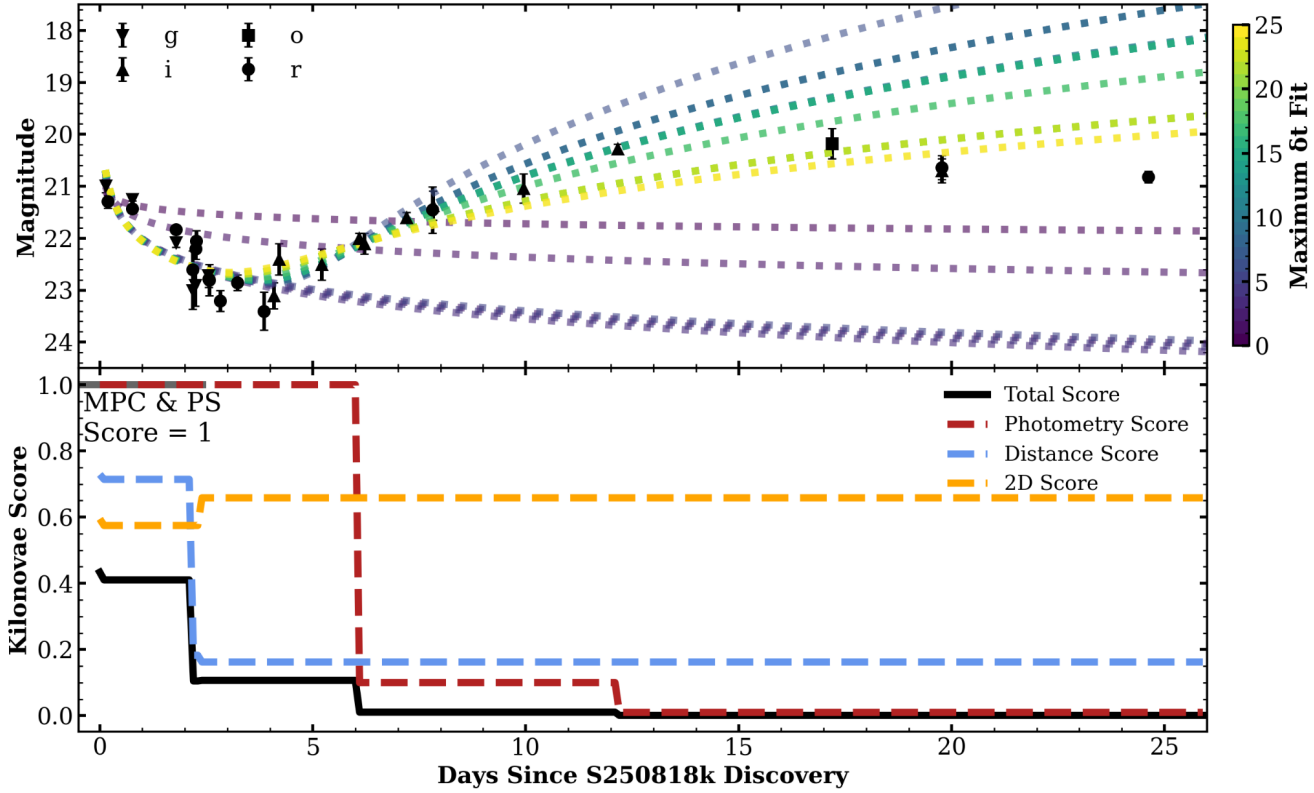
Franz+2025

Extra Slides

- SN2025ulz is photometrically and spectroscopically similar to other SN IIb

- Assume it was the counterpart to S250818k and detectable at 250 Mpc by LVK
  - There are **86 SN IIb at z<0.055** (~250 Mpc) during O4
  - **61 likely observable** to LVK at point of core collapse
  - Either some fraction of these events should have GW counterparts or SN2025ulz is exceptional in some way unobservable in the optical/IR

Application to 2025ulz



Franz+25
(Accepted)