



The Multi-messenger Treasure TROVE applied to Candidate Subsolar Mass Merger $S251112cm$

Northwestern



**NSERC
CRSNG**



Nick Vieira

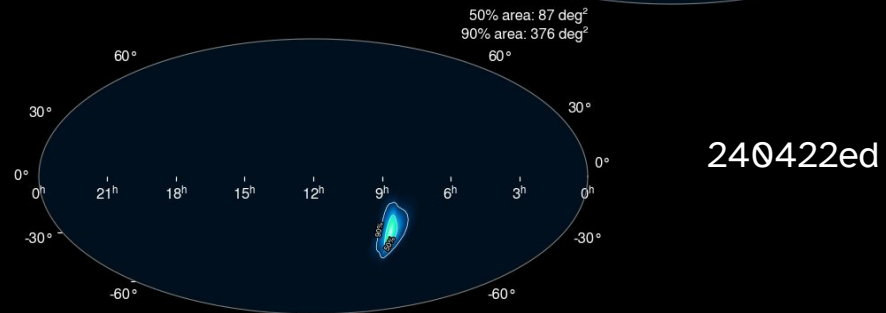
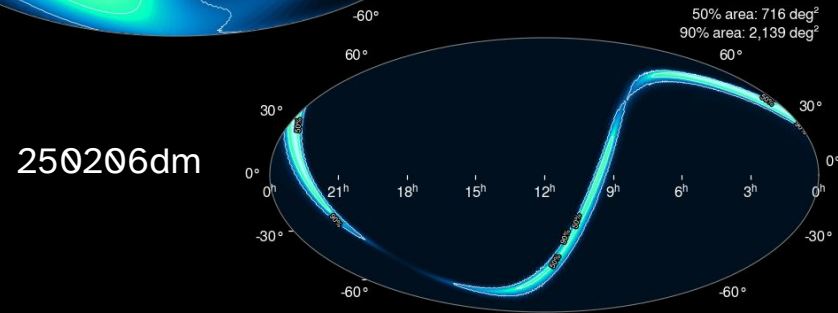
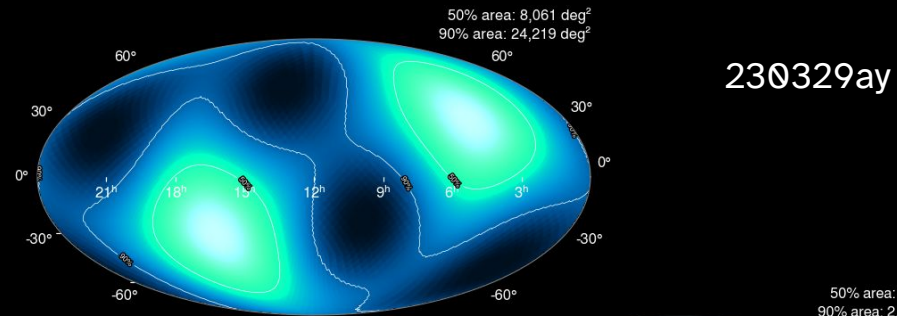
NSERC Postdoctoral Fellow @ CIERA

Empowering Science in the Data-Rich Era of
Astronomy | Tucson, AZ

22 April 2026

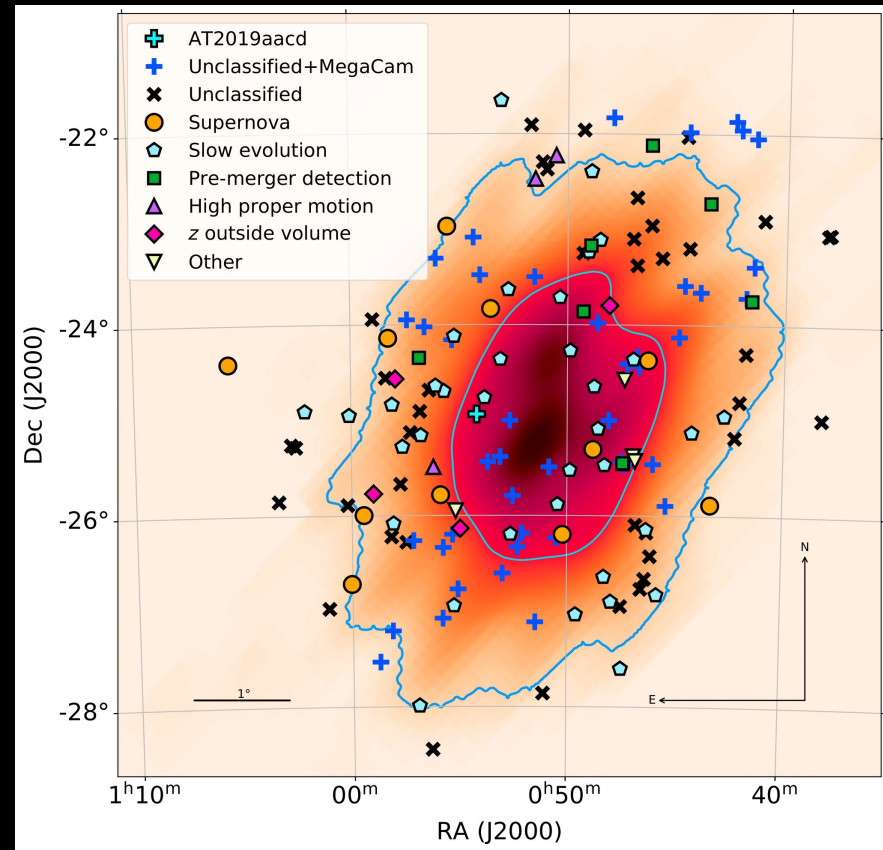
GW + EM astrophysics is challenging

Gravitational waves from binary
neutron star / neutron star + black
hole mergers produce large
localization regions with
confidence regions $\sim 10^2 - 10^3$ deg



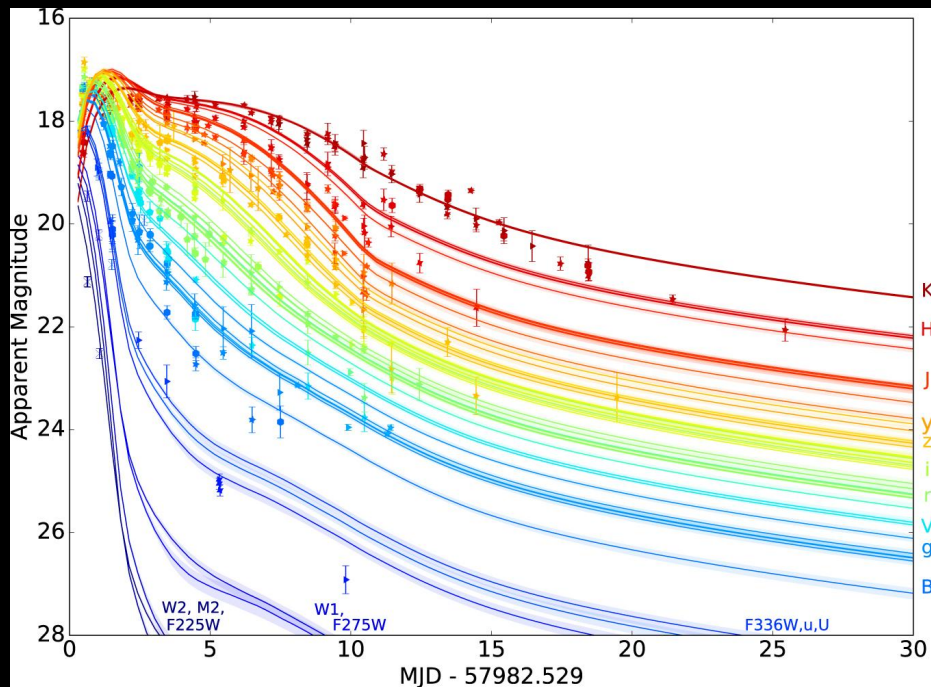
GW + EM astrophysics is challenging

Even exceptionally well-localized events like GW190814 will have dozens of candidate counterparts in their localization region—many never classified!



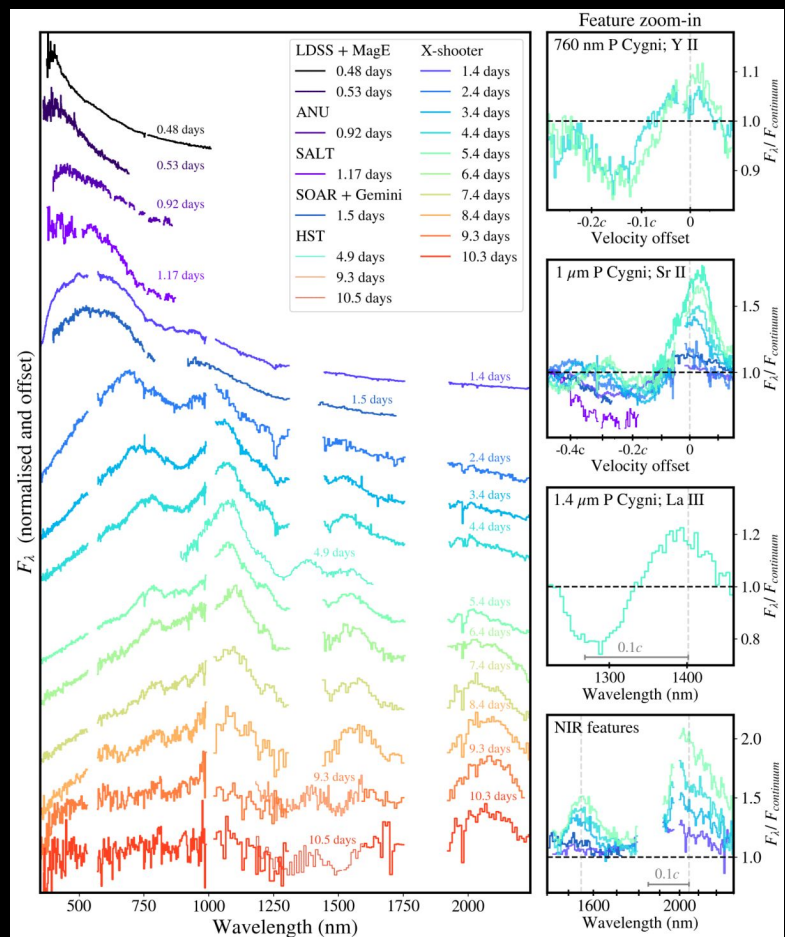
Vieira+20

...but fruitful!



Villar+17

Sneppen+24



Multimessenger tools

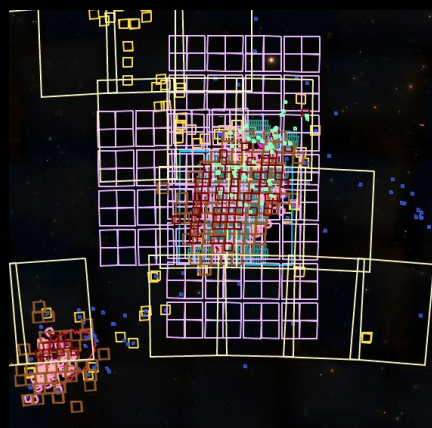
Welcome to TNS Version 2.0.

Please do not hesitate to contact the TNS admins if encountering any issues.

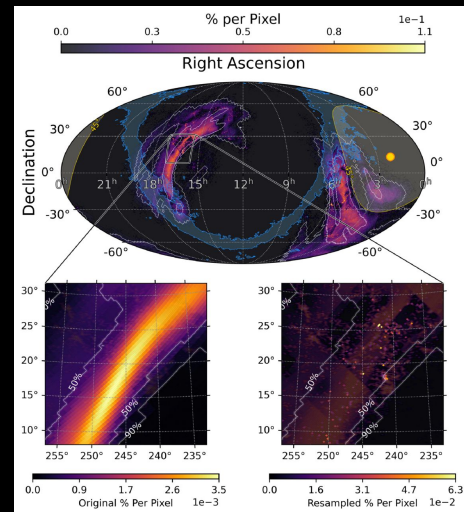
Search by name or coordinates (within 10")

Submit

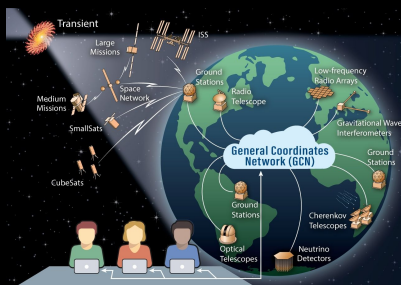
Transient Name Server



GW Treasure Map



General Coordinates Network



teglon



Target and
Observation
Managers

and brokers!



ALeRCE

Automatic Learning for the
Rapid Classification of Events



Babamul



Ampel

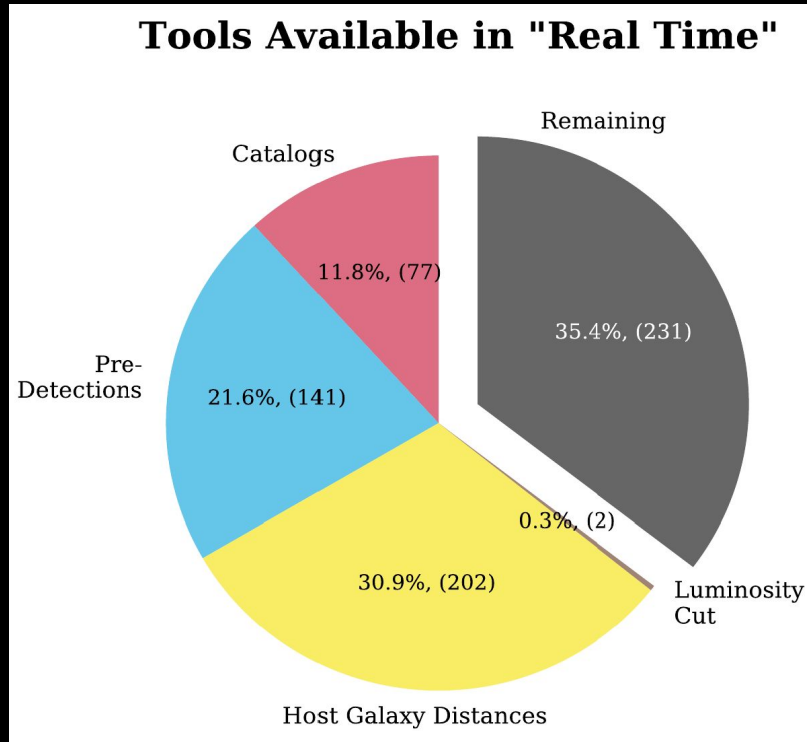
Lasair

ANTARES



Pitt-Google-Broker

How do we vet candidates?



Rastinejad+22

One can disqualify many candidate counterparts to an event using archival/real-time information (e.g., Anand+21, Kilpatrick+21, Rastinejad+22)

TROVE: Tool for Rapid Object Vetting and Examination

Assign each candidate a score [0.0, 1.0] based on:

- 2D position in localization
- 3D position (distance)
- association with nearby point sources or minor planets
- association with AGN
- photometric behaviour



TROVE is
NSF-funded from
a one-time call
for multi-
messenger
programs.



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Michael Lundquist
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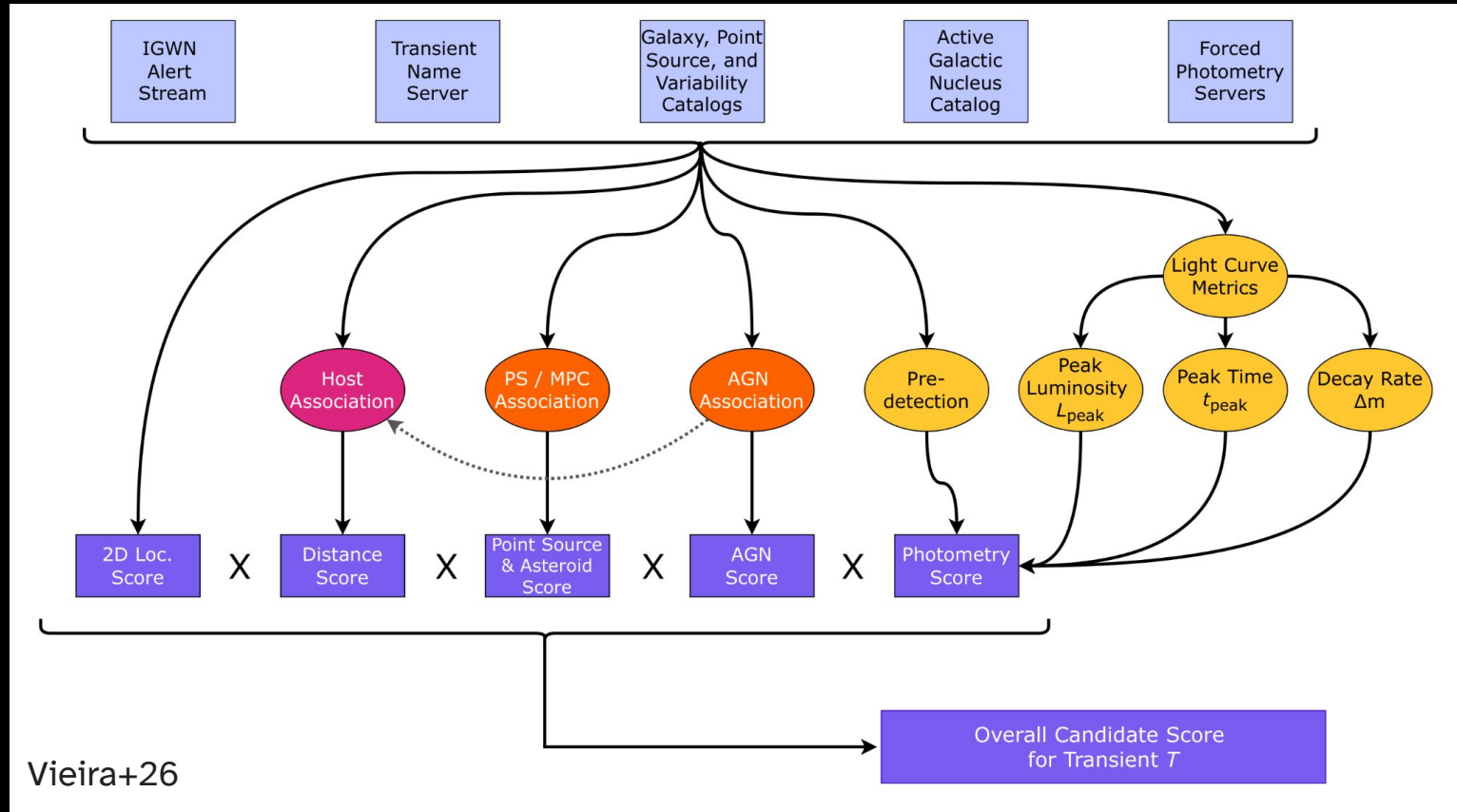


Bhagya Subrayan
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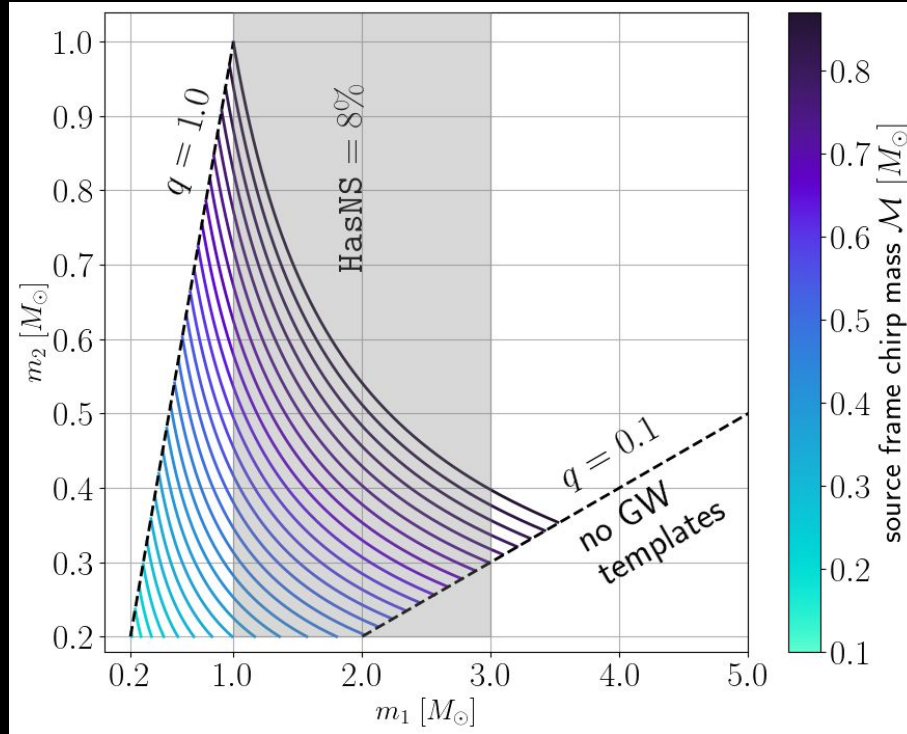


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TROVE: Tool for Rapid Object Vetting and Examination



S25112cm: a subsolar mass merger



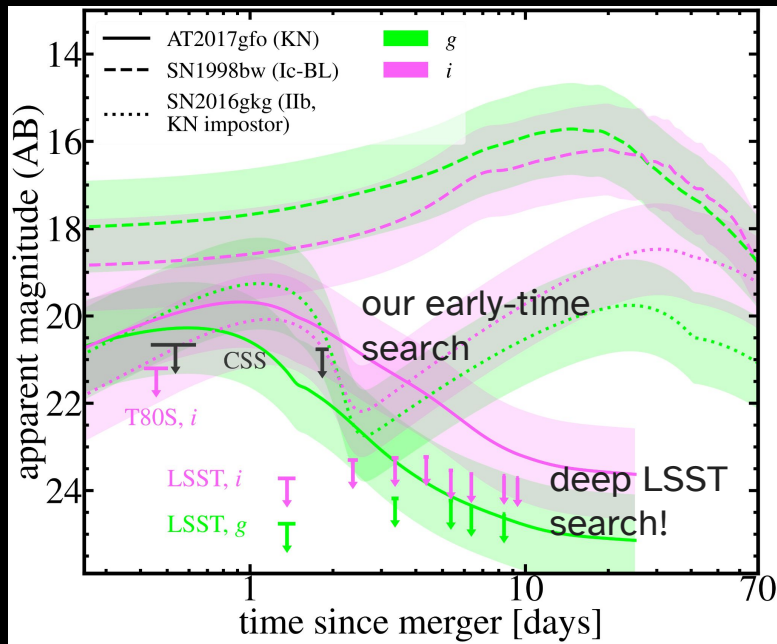
Vieira+26

Merger involving one or two subsolar mass objects, unlikely to contain an object of $1-3 M_\odot$

FAR of 1 in 6.2 (1 in 4?) years

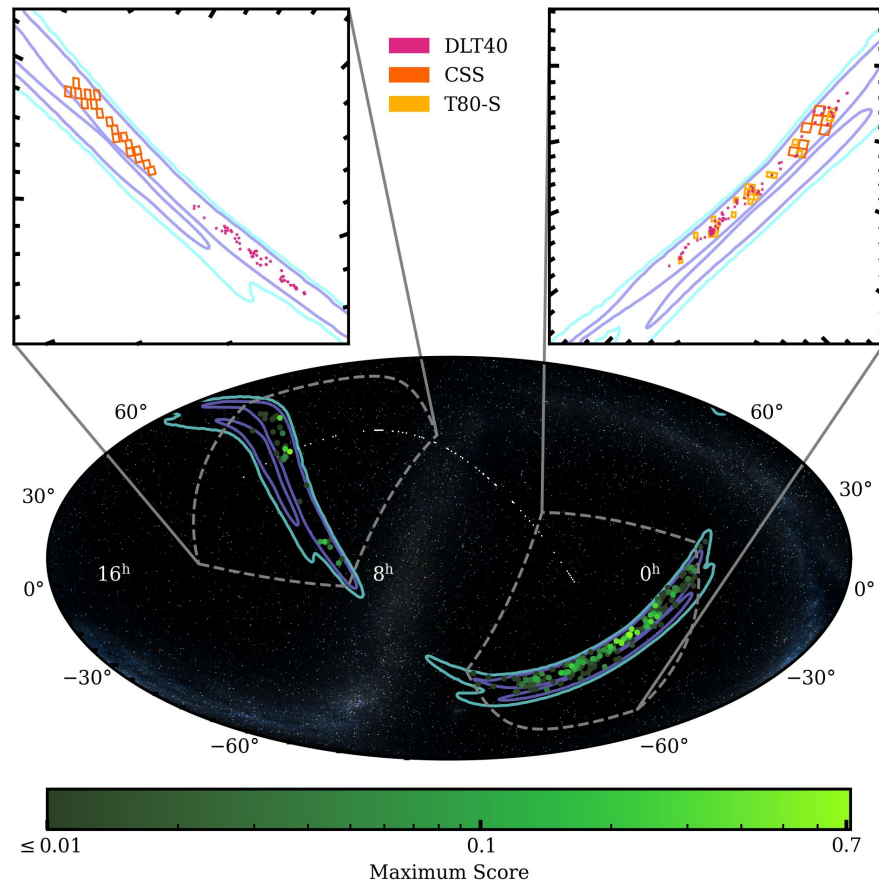
High Bayes coherence factor between LIGO-Hanford, LIGO-Livingston, and Virgo

S25112cm: follow-up

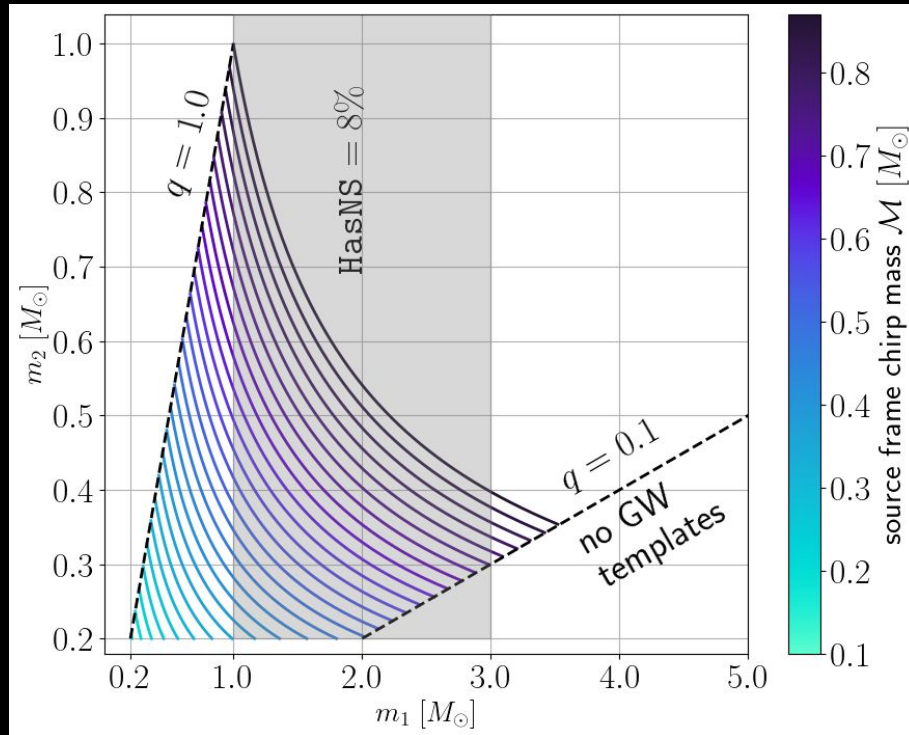


Vieira+26

Rubin data: MacBride+25, Anand+25



What are we looking for?



Vieira+26

Maybe ssNSs / ssBHs binaries exist in nature and produce **kilonovae**.

One theorized channel: eccentric NS-BH binary in which BH strips NS on first pass, renders the NS subsolar, and they then merge (East+15)

Where else might we form ssNS / ssBHs?

Fragmentation in collapsar disks

Collapse of a massive, rapidly rotating star; clumps in remnant BH accretion disk; condense to SSM objects which merge

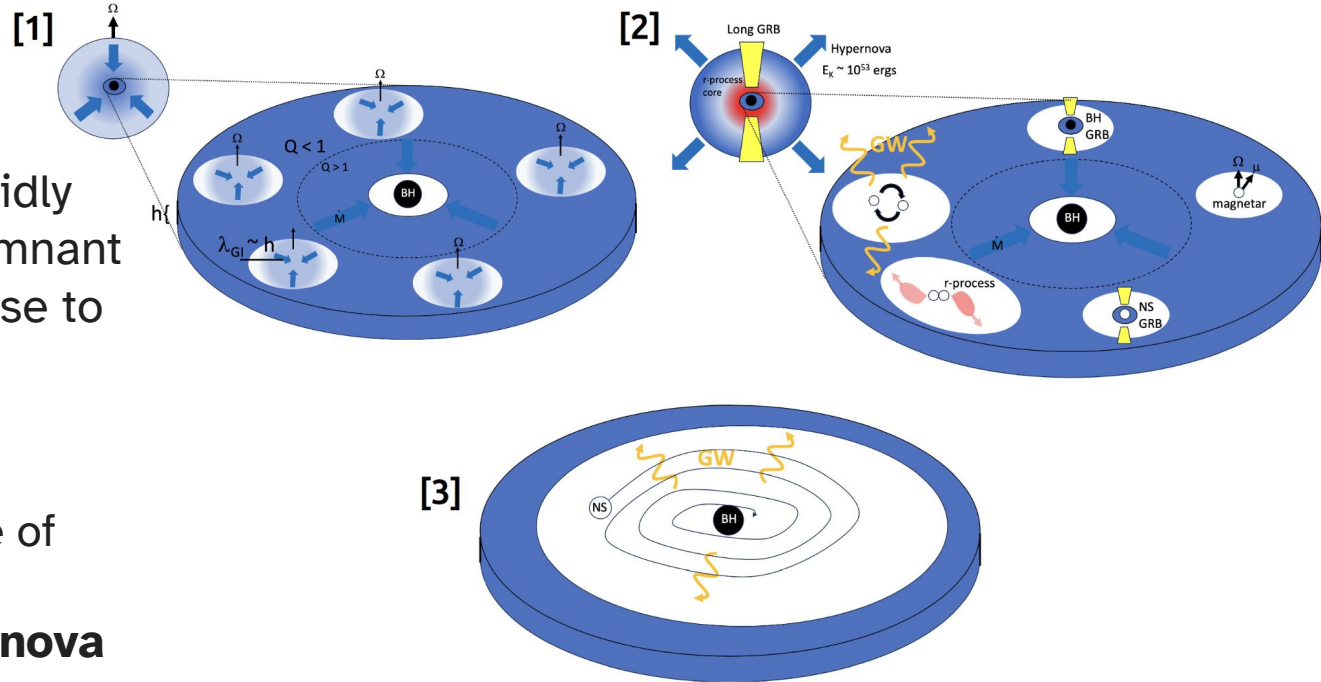
Two mass regimes:

1 - $10 M_{\odot}$ disk; KN is source of *r*-process material

→ **kilonova-within-supernova**

10 - $50 M_{\odot}$ disk; *r*-process in disk winds themselves

→ **super-kilonova**



Metzger+24

See also Chen & Metzger 25,

Lerner+26

Different transients → different photometry metrics

Table 2. Metrics for Computing Photometry Subscore

GW progenitor	EM signature	pre-detections allowed?	L_{peak} [erg s ⁻¹]	t_{peak} [days]	Δm [mag day ⁻¹]
BNS / NS+BH merger	KN	no	$< 10^{43}$	< 4	> 0.1
ssNS merger in $\sim 1 - 10 M_{\odot}$ collapsar disk	KN-in-SN ^a \approx SESN	< 1 day	$[5 \times 10^{41}, 10^{44}]$	< 35	$[-2.0, +0.1]$
ssNS merger in $\sim 10 - 50 M_{\odot}$ collapsar disk	super-KN ^b	< 1 day	$[10^{41}, 10^{43}]$	$[10, 70]$	-
BBH merger in AGN disk	AGN flare	yes	-	-	-

NOTE—Photometry constraints (whether pre-GW detection is allowed, and allowed peak luminosities, rise times, and decay rates), for different classes of EM transient which could accompany a particular GW progenitor. Where left empty with ‘-’, the metric is not usefully constrained by available observations or models.

^aB. D. Metzger et al. (2024) and Y.-X. Chen & B. D. Metzger (2025)

^bD. M. Siegel et al. (2022)

we cannot usefully constrain photometry metrics, and only 2 candidates associated with AGN.

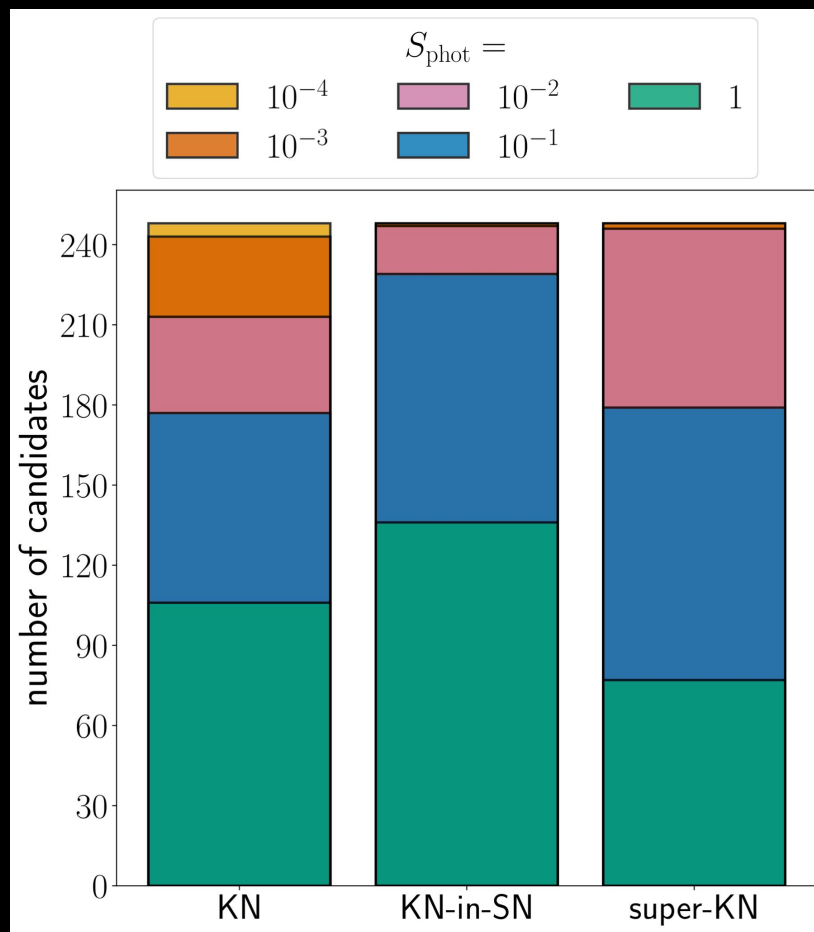
Different metrics → different scores

248 candidates (218 optical, 30 X-ray)

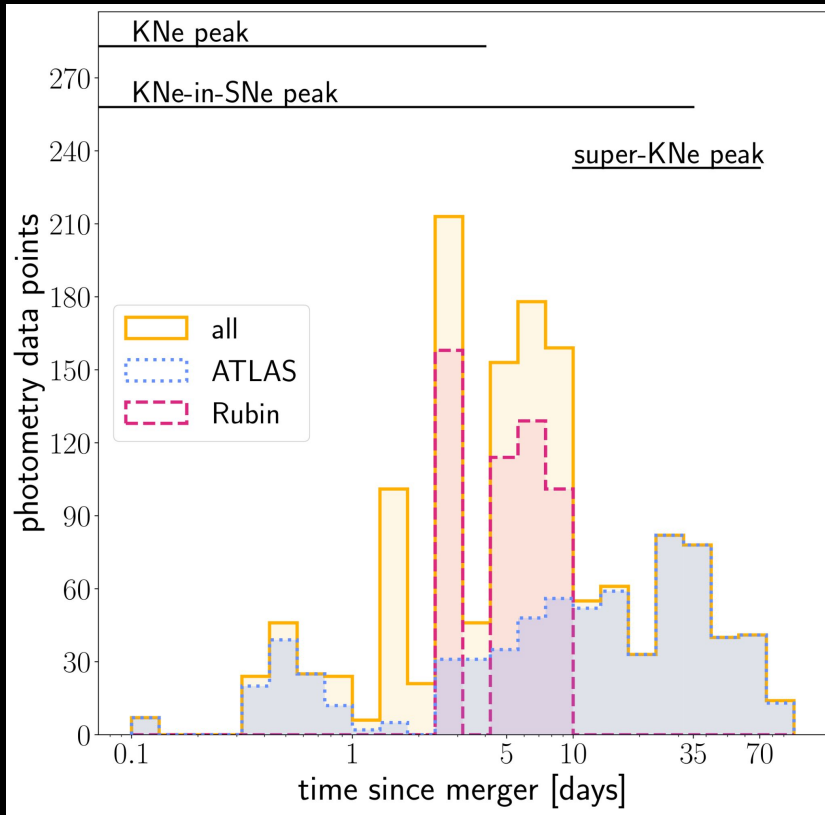
Candidates have different KN, KN-in-SN, and super-KN scores

E.g. broad metrics allowed for KNe-in-SNe mean that >half fall within our defined ranges, while that number is only ~a quarter for super-KNe.

Vieira+26



A lack of information drives scores



Vieira+26

Some (10) candidates have no distance measurement

Some candidates have limited photometry; 78 with only one detection

Photometry concentrated at early times

No candidate clearly identified as a viable counterpart to S25112cm.

We're using Rubin data!

Rubin photometry from ~1-10 days post-merger brought our total number of ingested candidates from 181 to **248**.

a dozen optical, X-ray, gamma-ray observatories

Rubin alone!

Optimizing follow-up with tools like TROVE will be critical in the era of Rubin dramatically increasing numbers of candidates.

What we've learned:

- We can score candidates to optimize follow-up, differentiating between KNe, KNe-in-SNe, and super-KNe
- We can (should!) look for more than KNe from SSM GWs, and adapt our strategies for longer-term monitoring.
Rubin can play a key role in this follow-up.

What to expect from us:

- **A call for testers!**
- TROVE 1.0 (infrastructure paper, web app, and API)
- TROVE 1.0 applied to O3 and O4 events
- Extensions to other poorly localized events
- Slack space for TROVE users
- Documentation & tutorials; workshops at conferences

Franz+25



[ApJL, 994,
2, L45](#)

Vieira+26



[arXiv:
2603.17009](#)

