The Gravitational-wave Optical Transient Observer (GOTO)

Joe Lyman
University of Warwick
on behalf of the GOTO collaboration

4th Astro-COLIBRI workshop

UNIVERSITY OF WARWICK | GOTO GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER | UKRI UK Research and Innovation

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EXPLORING THE COSMOS SINCE 1790
UNIVERSITY OF LEICESTER
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MANCHESTER 1824
The University of Manchester
UKRI Science and Technology Facilities Council

Science motivation

The Dynamic and multi-messenger Universe

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- Photons
- Cosmic rays
- Neutrinos
- Gravitational waves

Design specification

Multi-site optical wide-field sky survey

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- First proposed in 2014: a **dedicated** facility for the **EM follow-up of GW alerts**.
- Focus on **rapid response**, **wide-field** and **autonomous** control systems and analysis pipelines.
- Multiple unit-telescopes (UTs) and mounts for a modular observatory: **staged deployment**, **scaling** and **adaptability**

Prototype system

2017-2020 (Steeghs et al. 2022)

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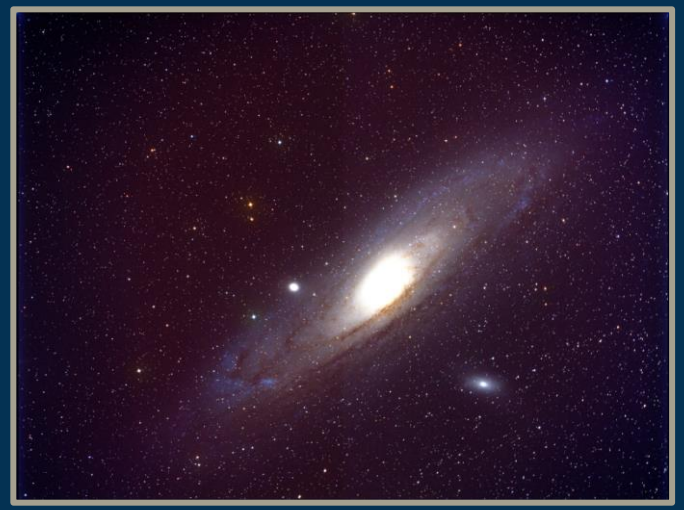
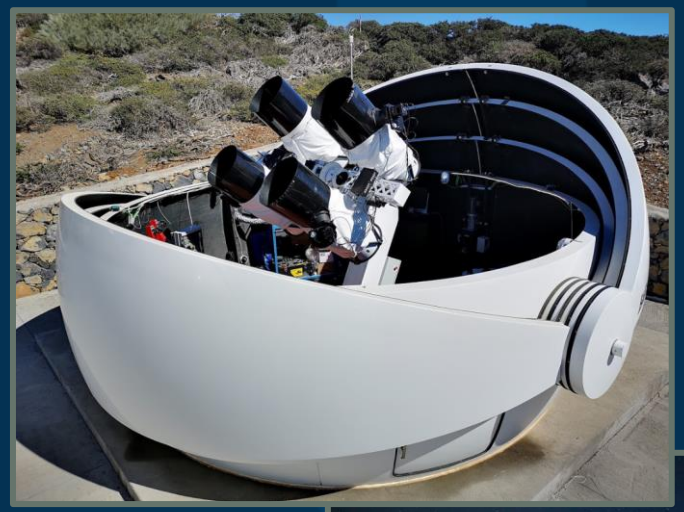
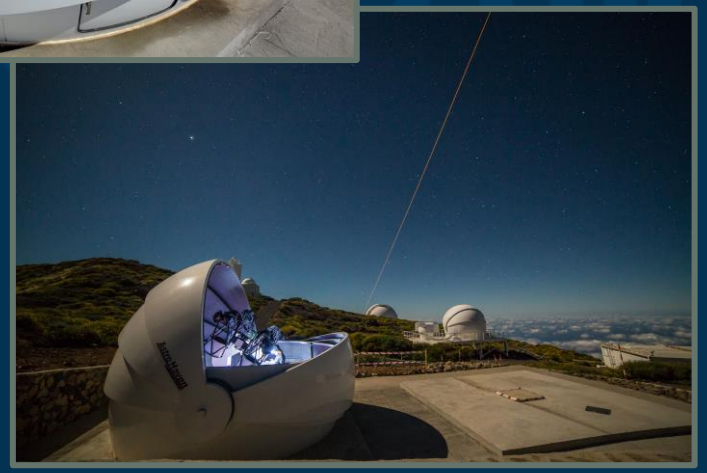
- **Four UTs,** one mount on **La Palma**
  - 40cm aperture, ~5.5 sq. deg. FoV per UT
- Expanded to include different OTA designs during commissioning to inform final design







Development

2020-2023

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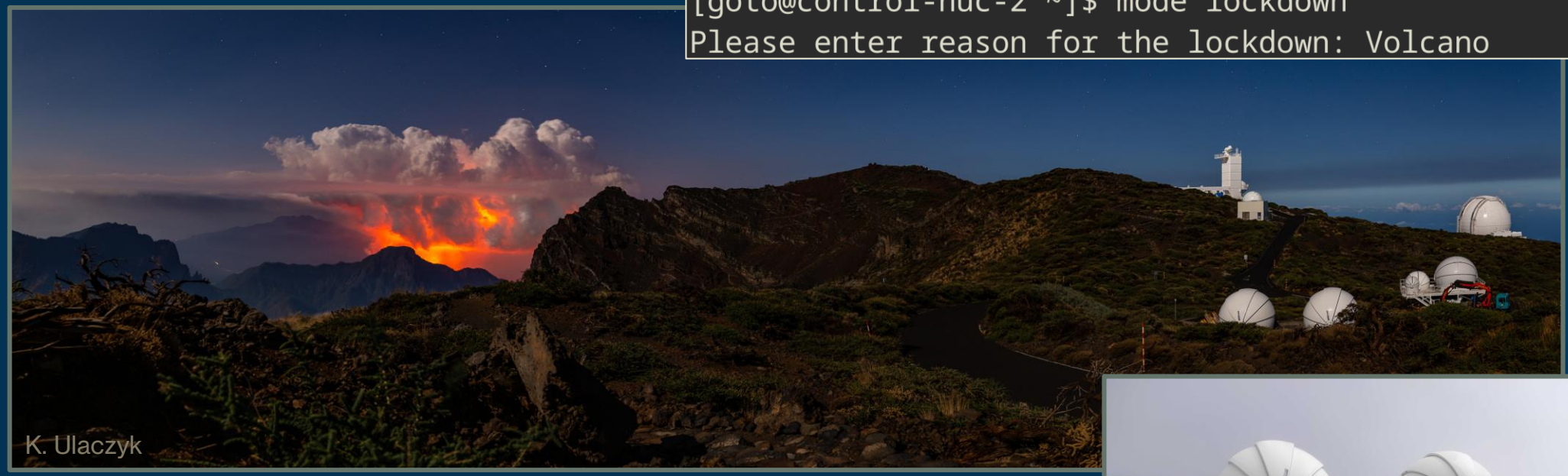

- [x] Pandemic
- [x] Volcano
- [x] Hail/Ice
- [ ] Locusts

Full Design

2023- (Steeghs et al. in prep.)

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- **Four mounts,** each holding **8 UTs**
- **Two nodes**, one in La Palma, one in Siding Spring
- **Improved OTA** and mount design
- Wide optical filter **L** (400-700nm)
- Fully **autonomous** scheduling and **real-time** pipeline

Full Design

2023- (Steeghs et al. in prep.)

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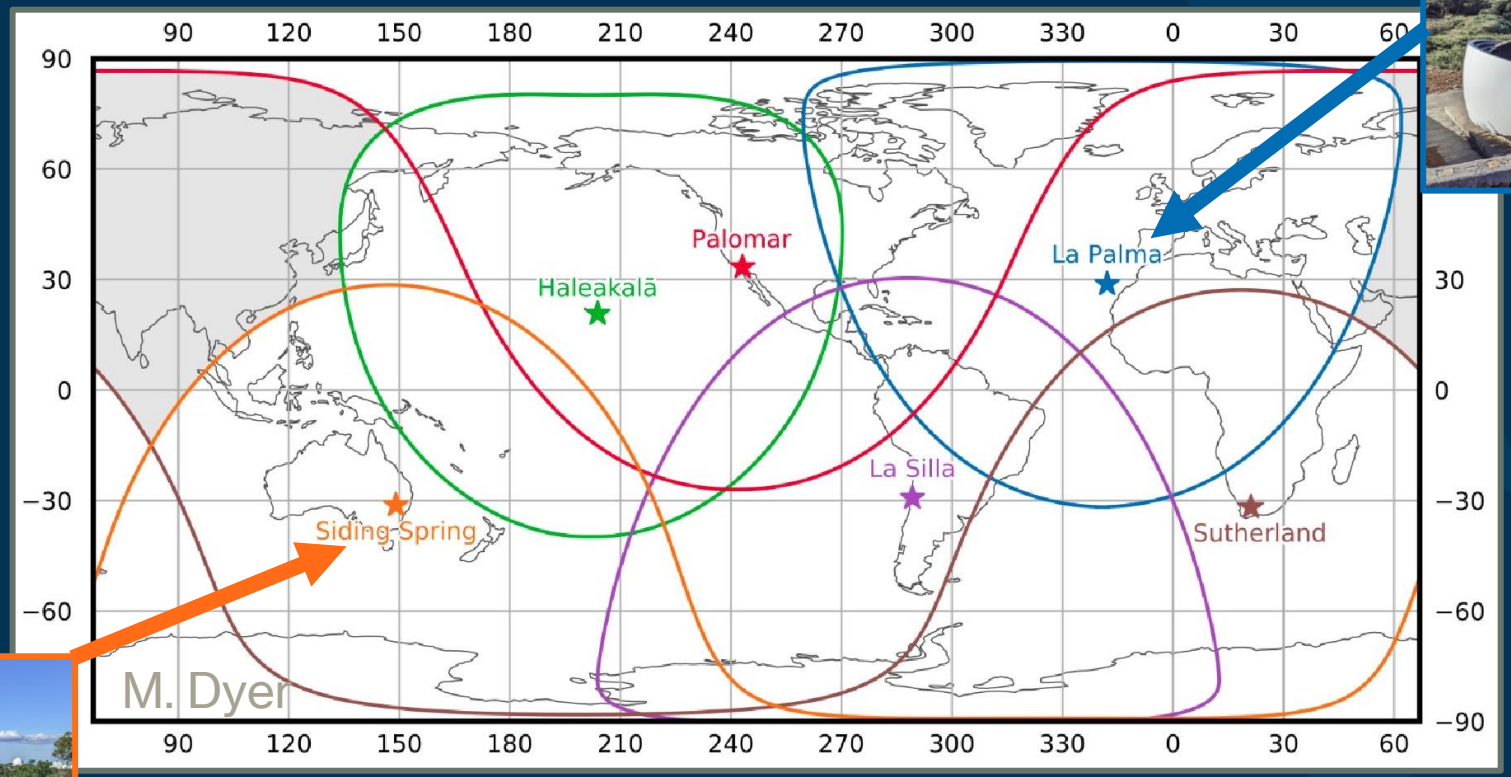

Full Design

2023- (Steeghs et al. in prep.)

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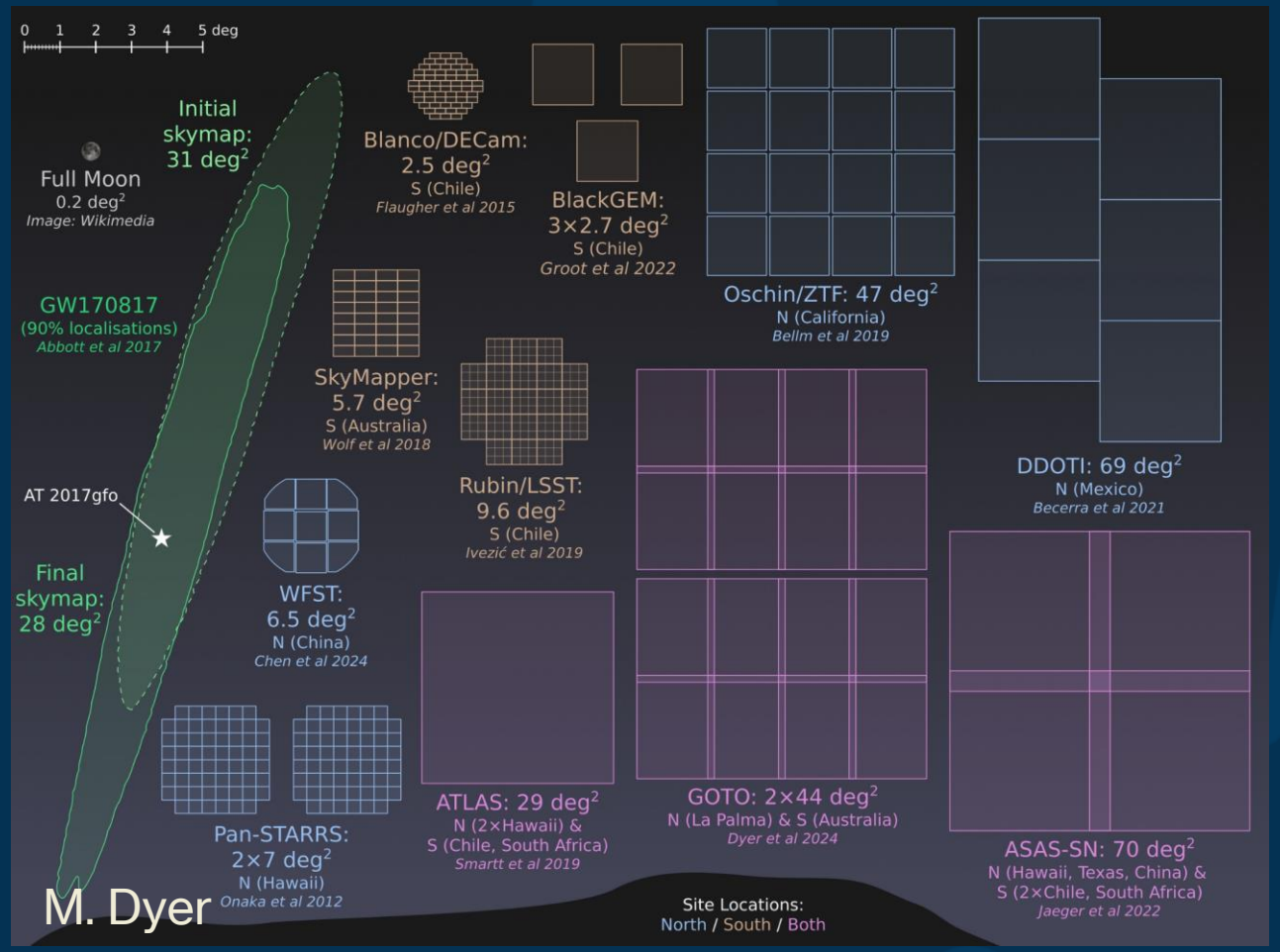
- **All-sky survey** with ~2d cadence on average
- Large areas of much higher cadence **(~hours)** when responding to triggers



Control and Scheduling

G-TeCS (Dyer et al. 2018, 2020, 2024)

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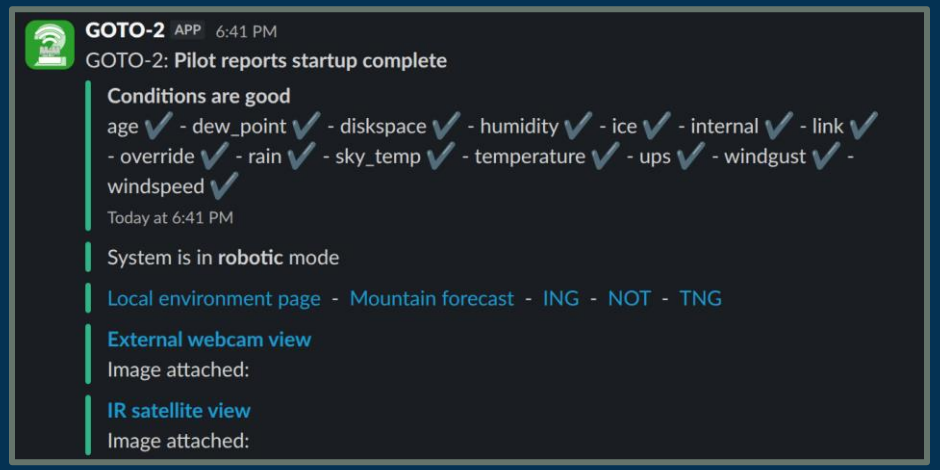
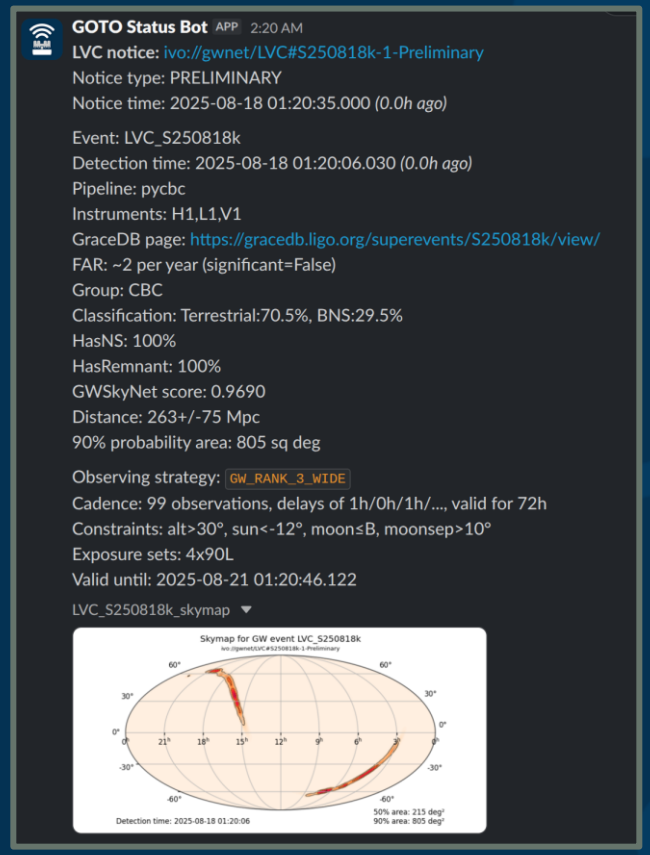
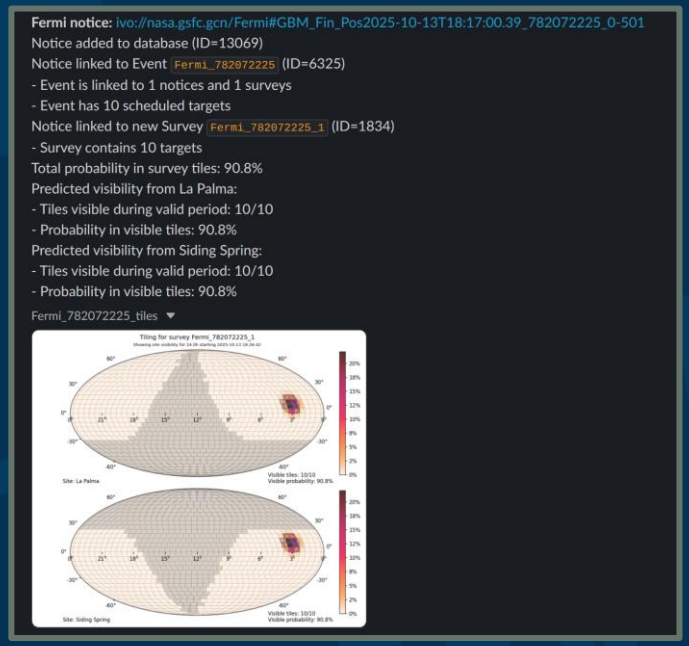
- All four mounts **fully autonomous and independent**
- **Automated processing** and classification of external alerts (GRB, GW, neutrino)
- **One central scheduler** responsible for enacting follow-up strategies and all-sky survey







Pipeline and Marshall

Lyman et al. (to be submitted)

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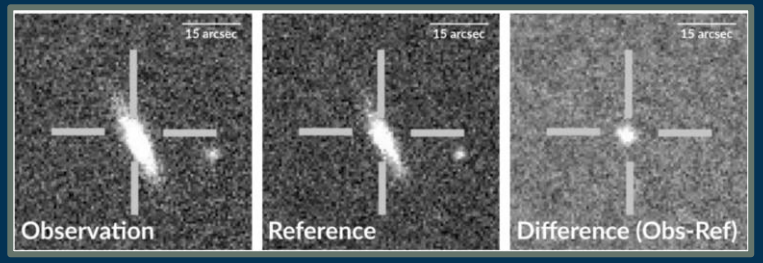

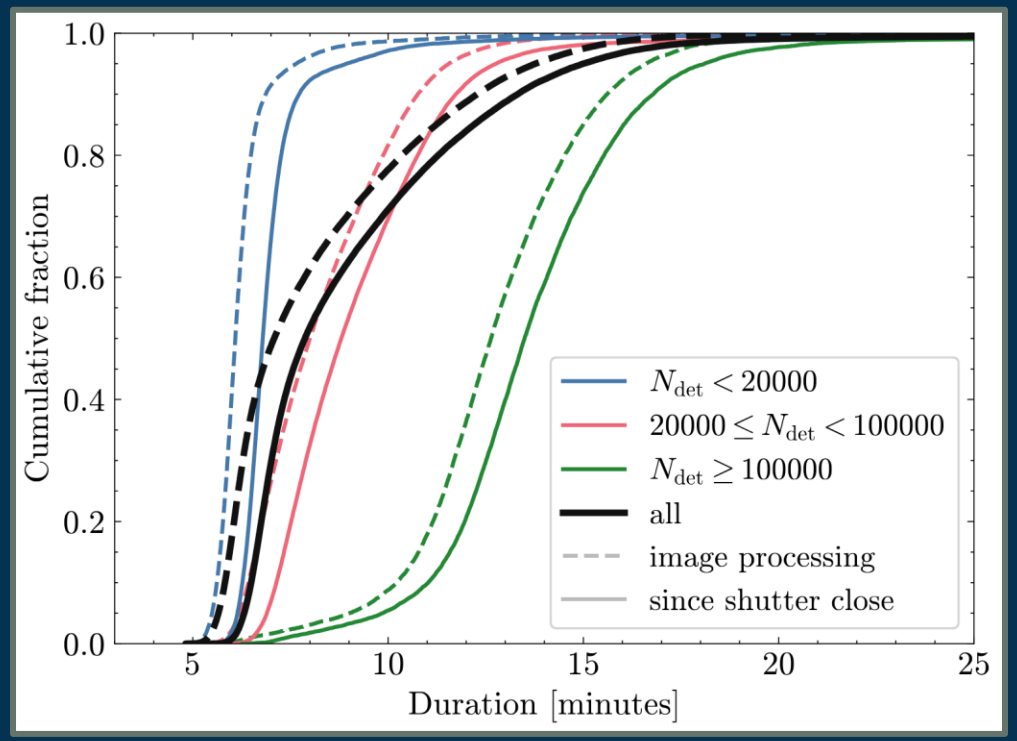

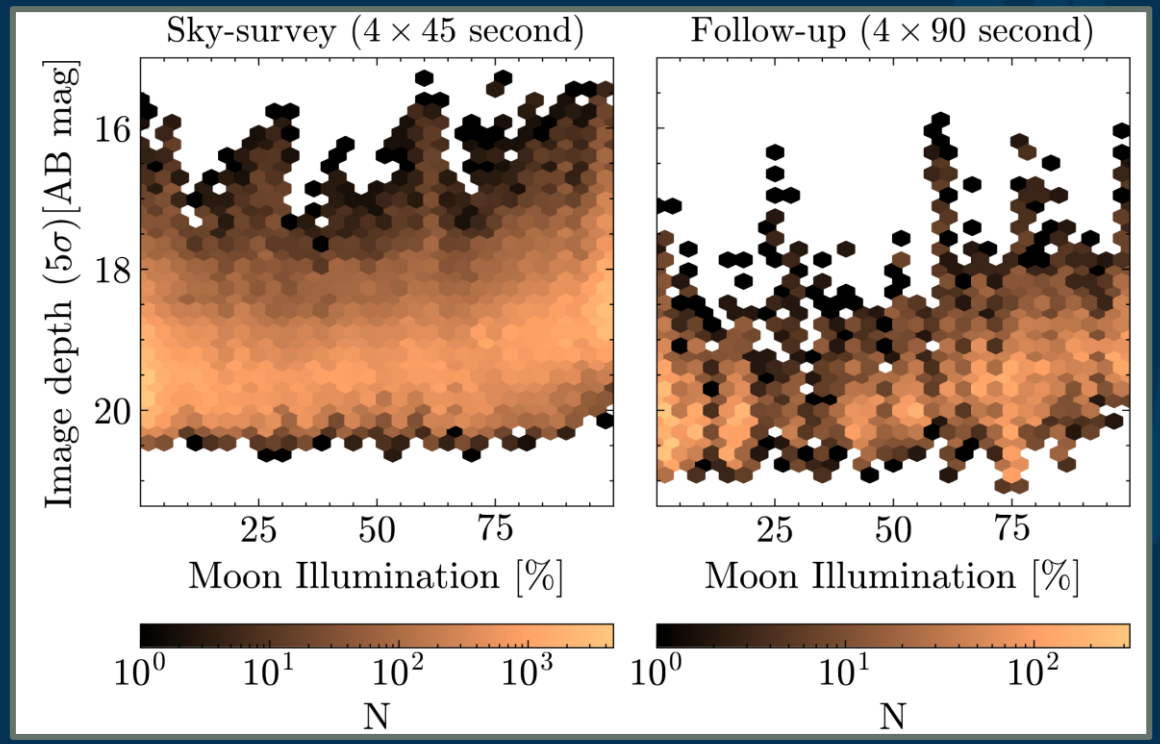

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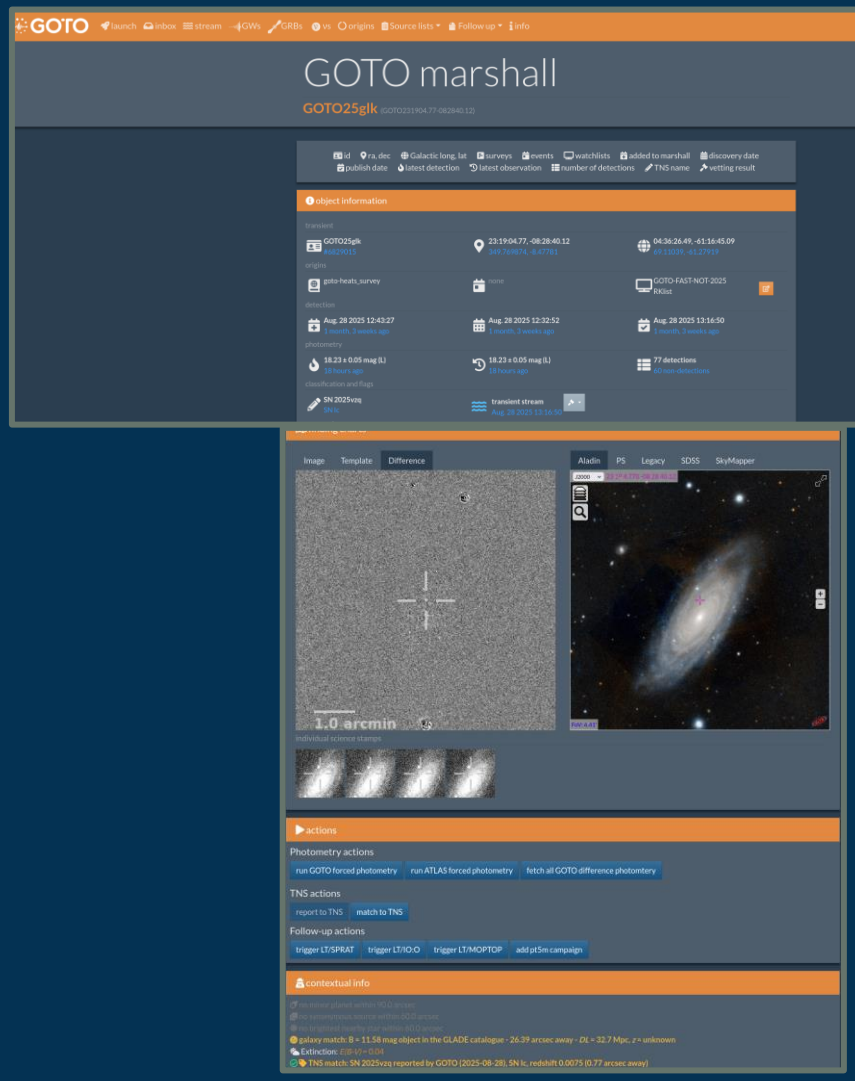

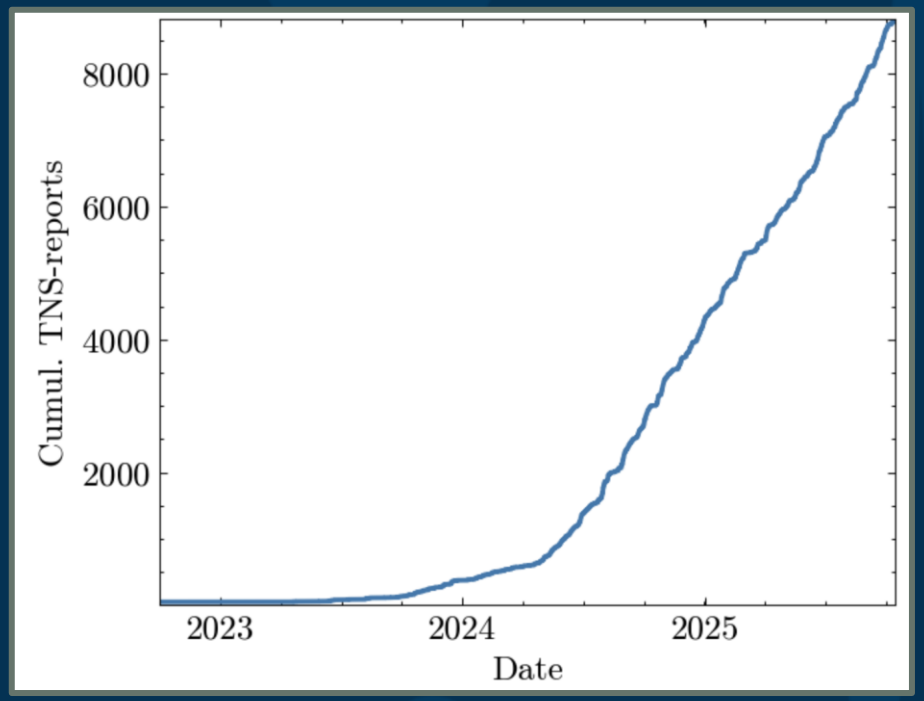

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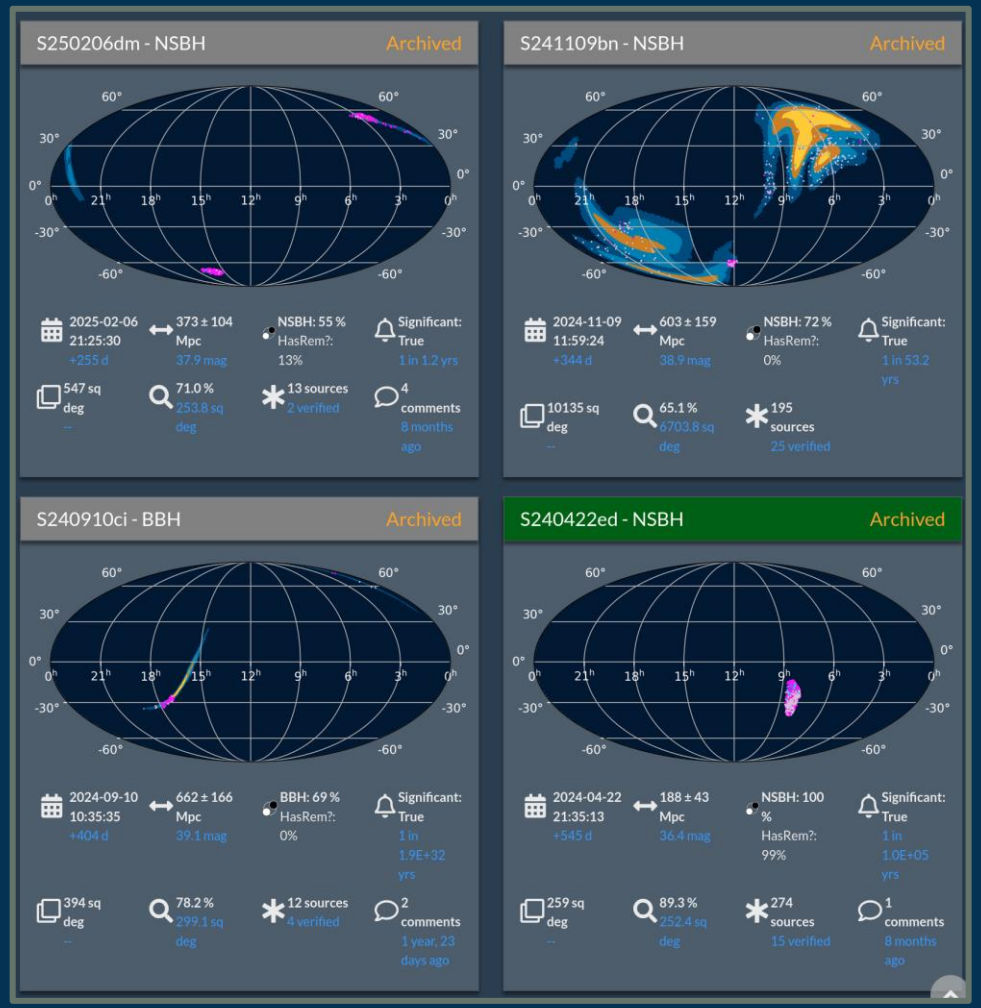

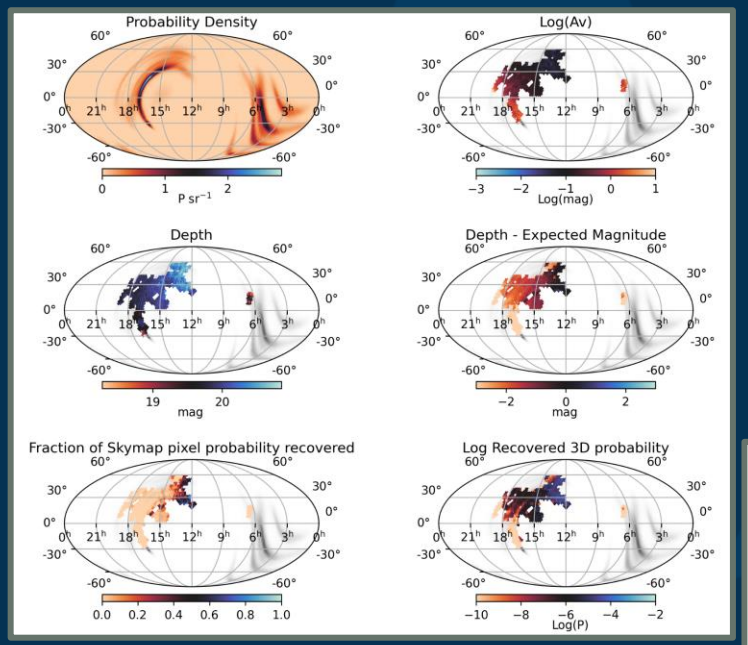

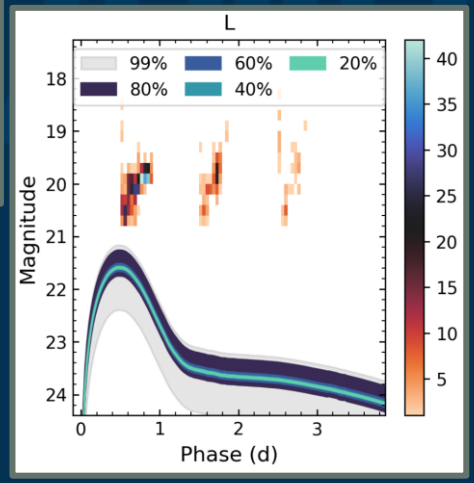

GeRRY (O'Neill et al. 2024)

GRB Afterglow localisation

Kumar et al. (2025); Dimple et al. (2025)

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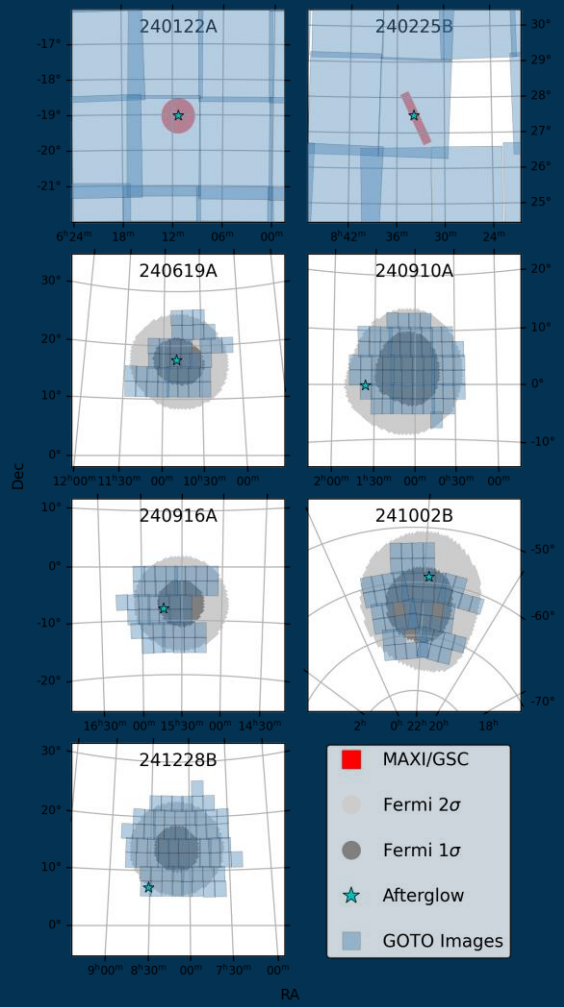

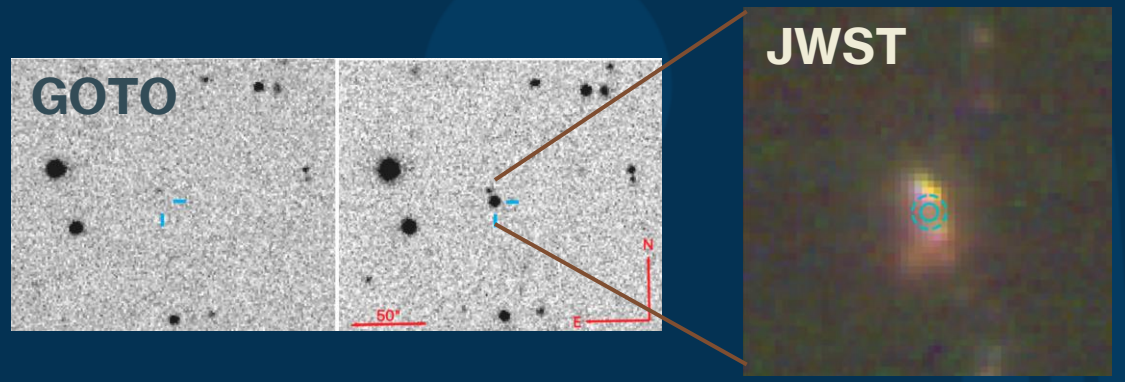

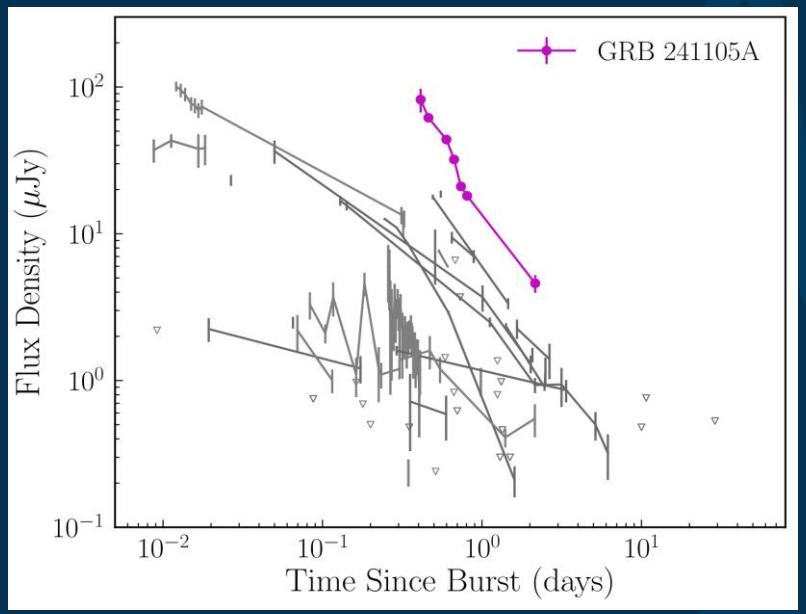

GRB orphan afterglow

Martin-Carrillo et al. (in prep)

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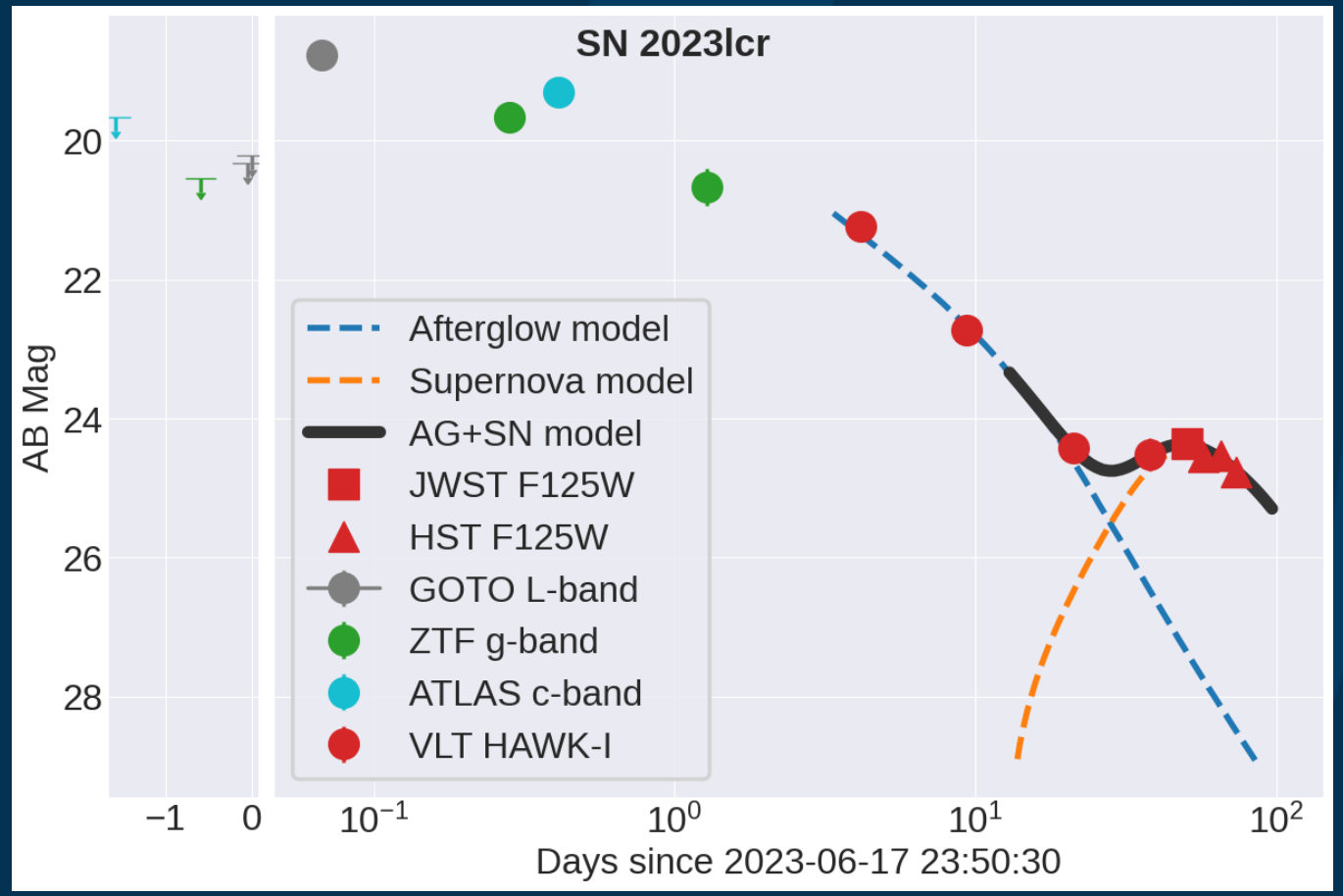
- **Fading transient** reported by **ZTF**
- **1.5 hour non-detection** window in **GOTO**
- **No high-energy** trigger coincident
- **HST/JWST follow-up confirm afterglow**
  - **JWST spectrum of SN at z~1!**



GOTO-FAST

Immediate spectroscopic follow-up of discoveries

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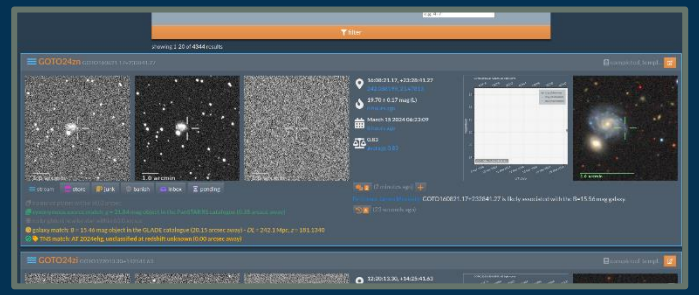
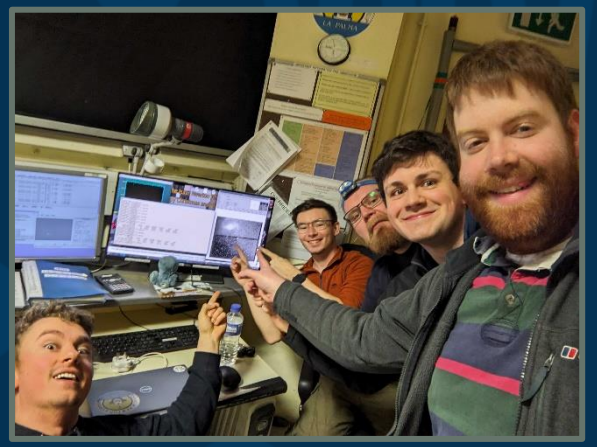


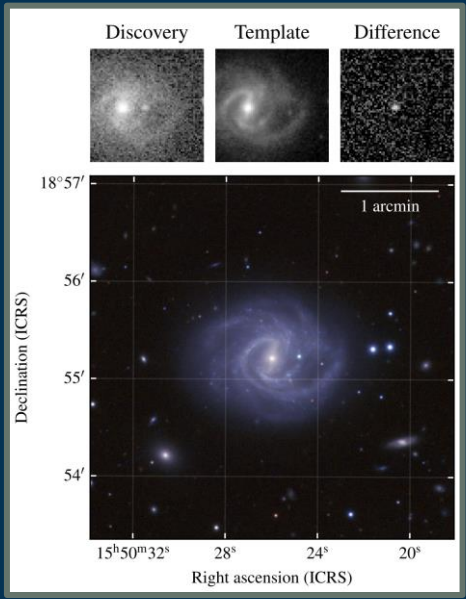


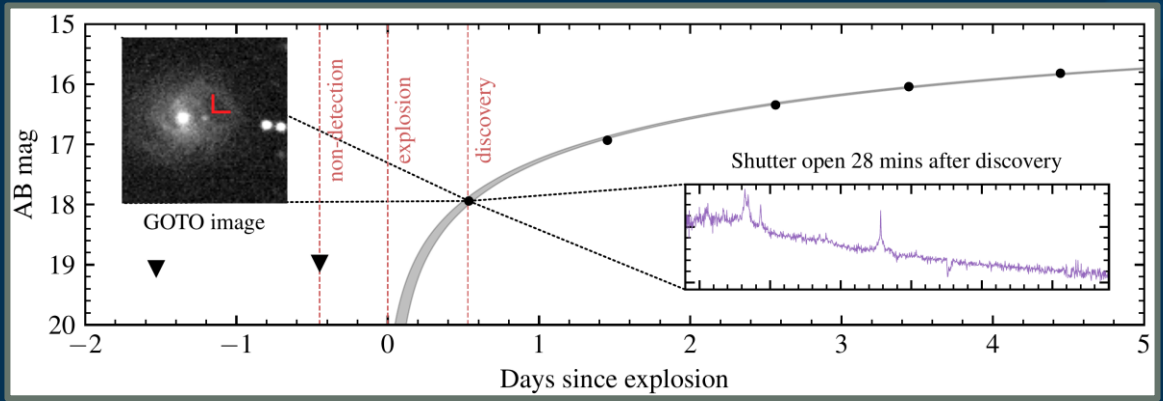
4th Astro-COLIBRI workshop – 20 October 2025

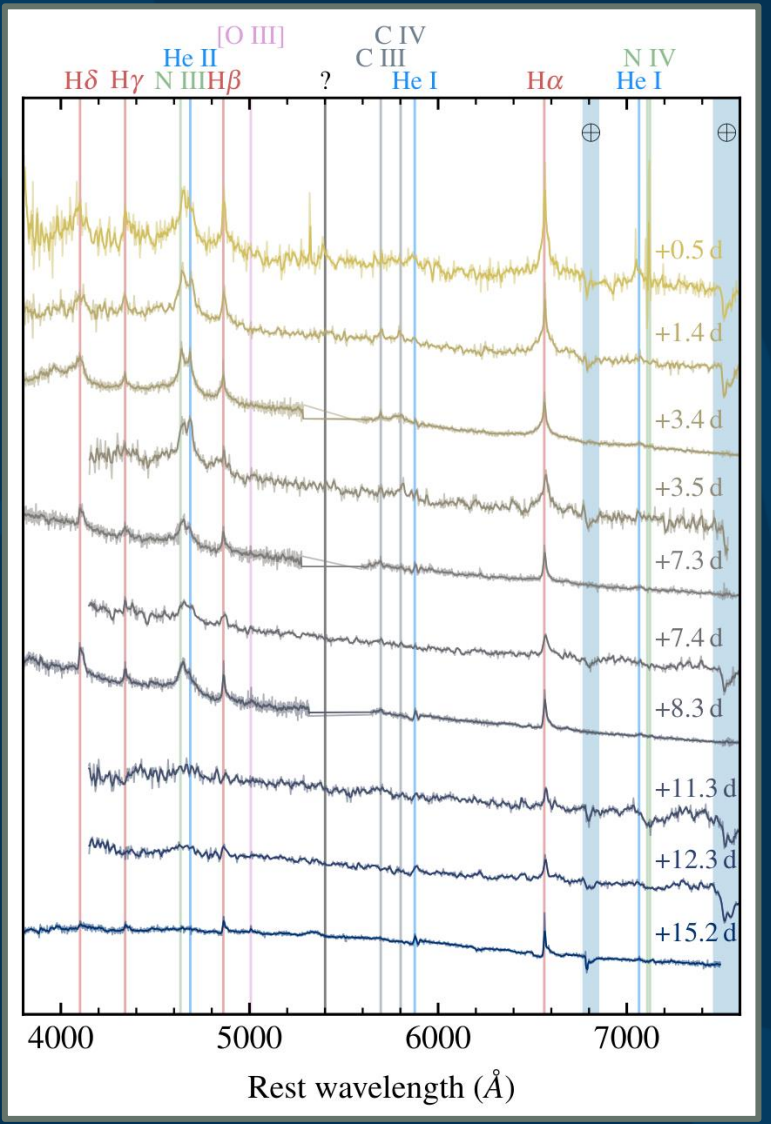
GOTO-FAST

SN2024cld – a complex RSG CSM environment and dust factory (Killestein et al. submitted + in prep)

- Three follow-up facilities triggered **within an hour** of discovery
- First spectrum **~12hr post-explosion**
- Still being observed **20 months later**







GOTO-FAST

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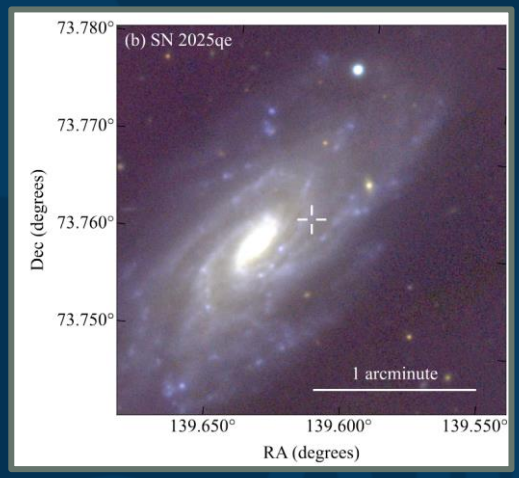
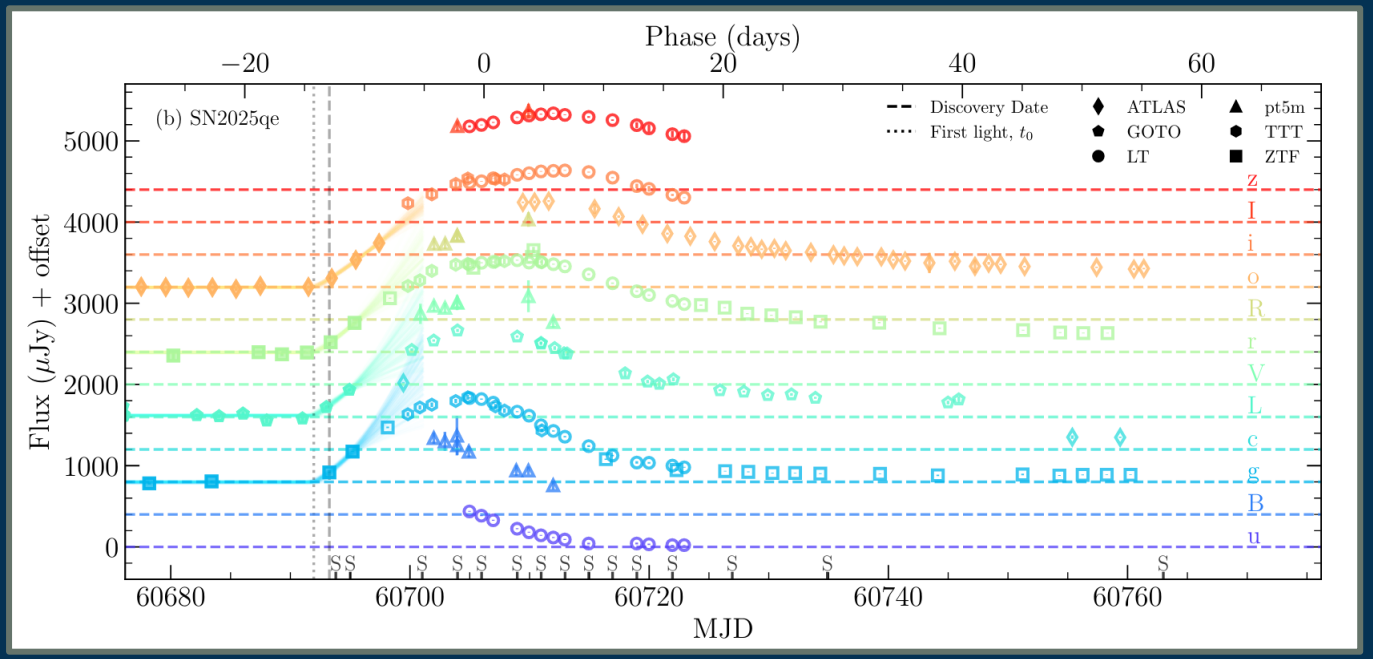
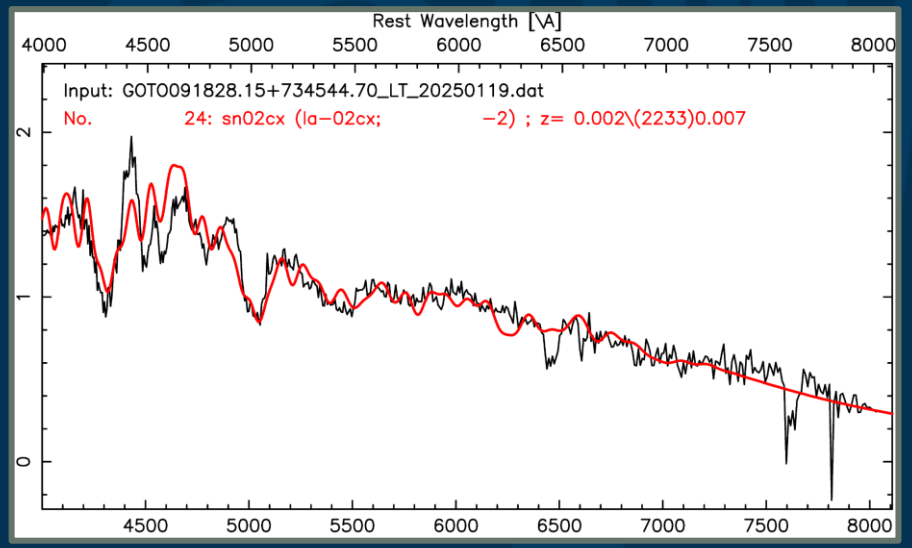
SN2025qe – automated spectroscopic follow-up of an infant SN Iax (Magee et al. 2025)

- **Automatic trigger** sent by GOTO Marshall to Liverpool Telescope upon discovery
- **Earliest** SN Iax classification spectrum







Citizen Science

Kilonova Seekers (Killestein, Kelsey et al. 2025)

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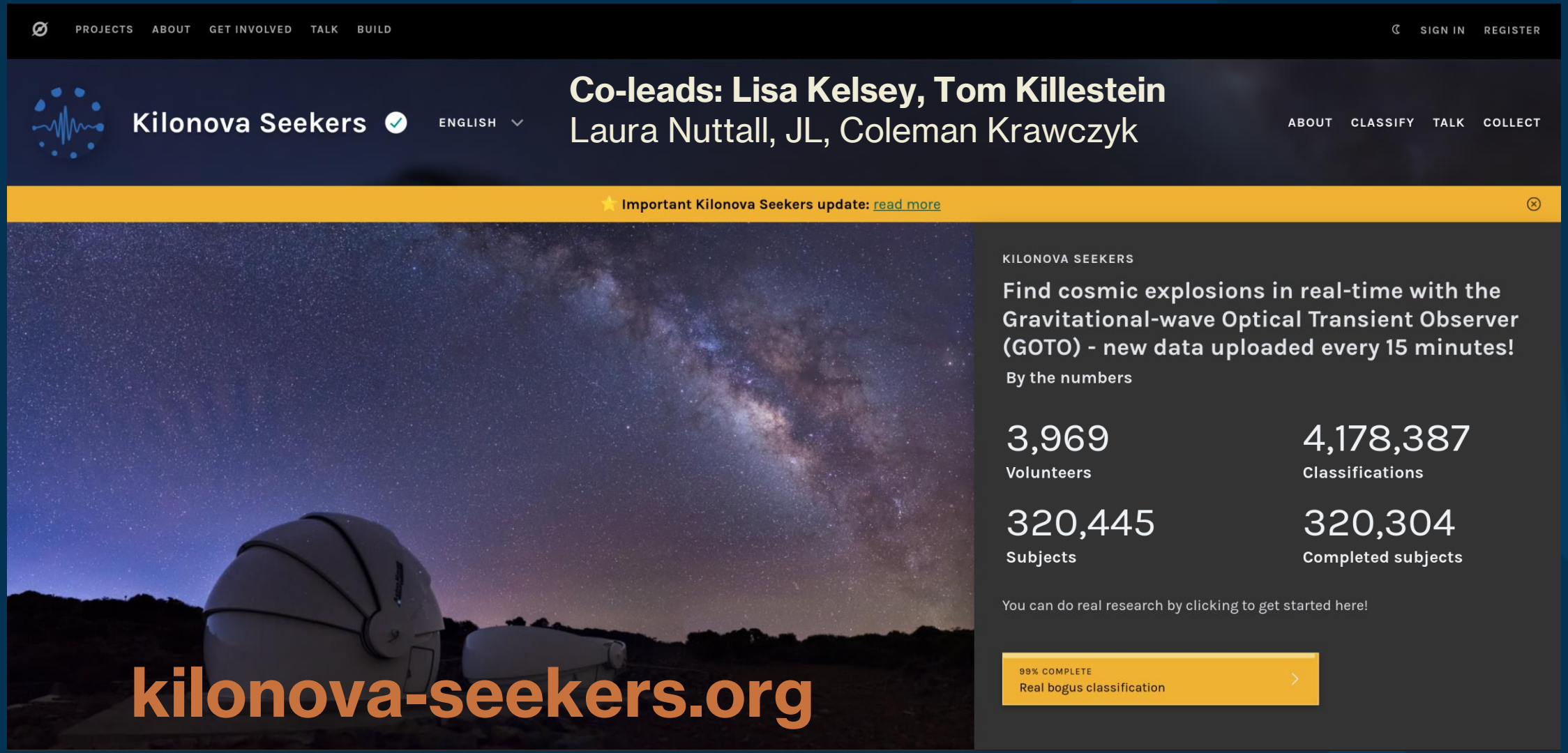

Citizen Science

A remarkable Dwarf Nova in Killestein et al. (incl. volunteers), 2025
Castro-Segura et al. (2025)

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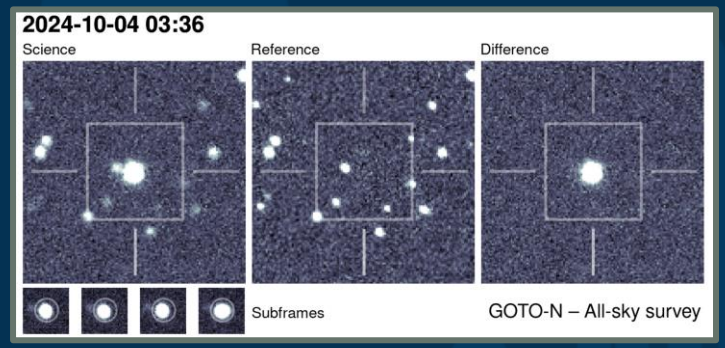
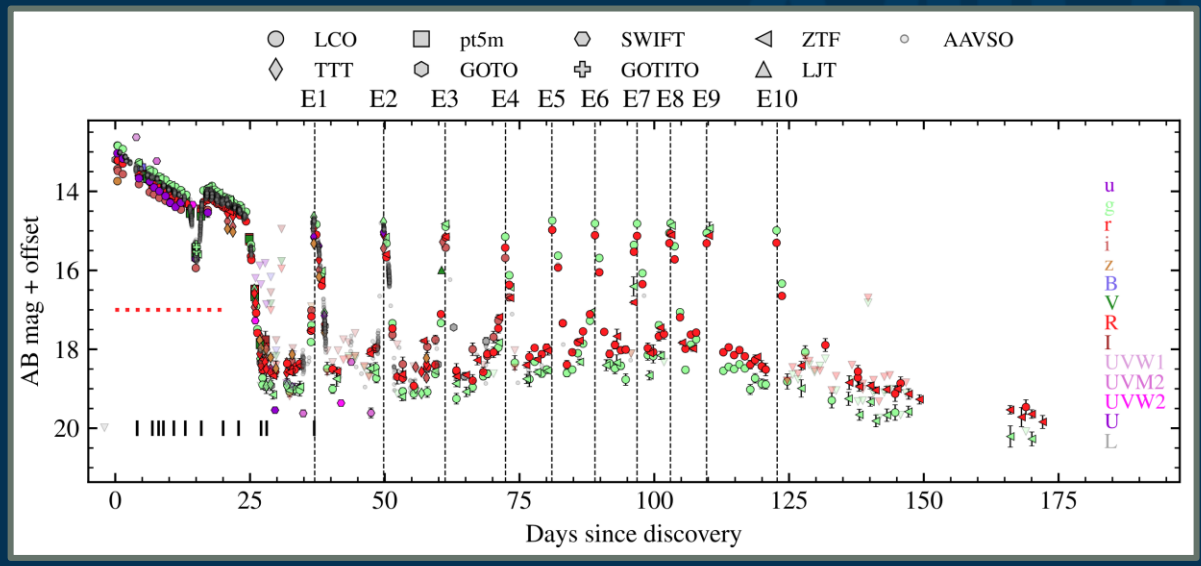
Discovered by, followed up, and written up with
citizen scientist volunteers

GOTO065054+593624: An 8.5 mag amplitude dwarf nova identified in real time via Kilonova Seekers

T. L. Killestein[1,2,*], G. Ramsay[3], M. Kennedy[4], L. Kelsey[5], D. Steeghs[2], S. Littlefair[6], B. Godson[2], J. Lyman[2], M. Pursiainen[2], B. Warwick[2], C. Krawczyk[7], L. K. Nuttall[7], E. Wickens[7], S. D. Alexandrov[8,9], C. M. da Silva[8,10,11], R. Leadbeater[12], K. Ackley[2], M. J. Dyer[6], F. Jiménez-Ibarra[13], K. Ulaczyk[2], D. K. Galloway[13], V. S. Dhillon[6,14], P. O'Brien[15], K. Noysena[16], R. Kotak[1], R. P. Breton[17], E. Pallé[14], D. Pollacco[2], A. Kumar[2,18], D. O'Neill[2], T. Butterley[19], R. Wilson[19], S. Mattila[1,20], A. Sahu[2], R. Starling[15], C. Y. Wang[21], Q. Liu[22], A. Li[23,24], Z. Dai[25,26], H. Feng[27], W. Yuan[28,29], R. Billington[8], A. G. Bull[8,30,31], S. Gaudenzi[8,10], V. Gonano[8], H. Krawczyk[8], M. T. Mazzucato[8,31,32], A. Pasqua[8], J. A. da Silva Campos[8,33], M. Torres-Guerrero[8], N. N. Antonov[34], S. J. Bean[12], E. T. Boeneker[10], S. M. Brincat[10], G. S. Darlington[12,10], F. Dubois[35,36], F.-J. Hambsch[36,10,37,38], D. Messier[10,39], A. Oksanen[10,40], G. Poyner[12], F. D. Romanov[10,41], I. D. Sharp[12], T. Tordai[42], T. Vanmunster[10,39], and K. Wenzel[38]



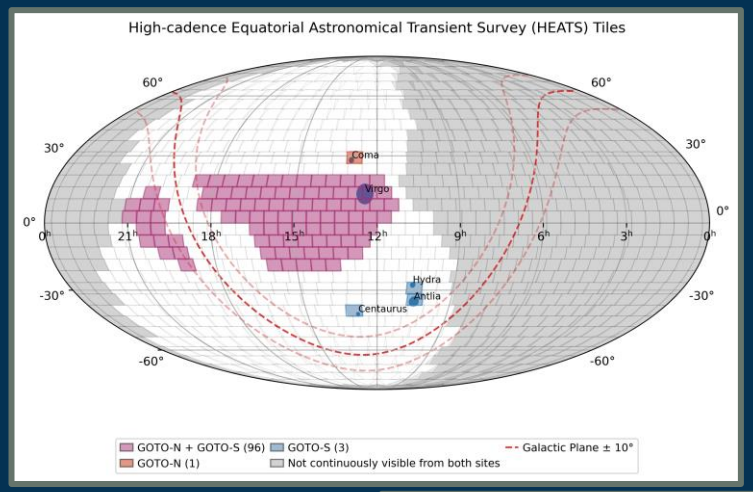


Post O4

(~1 month)

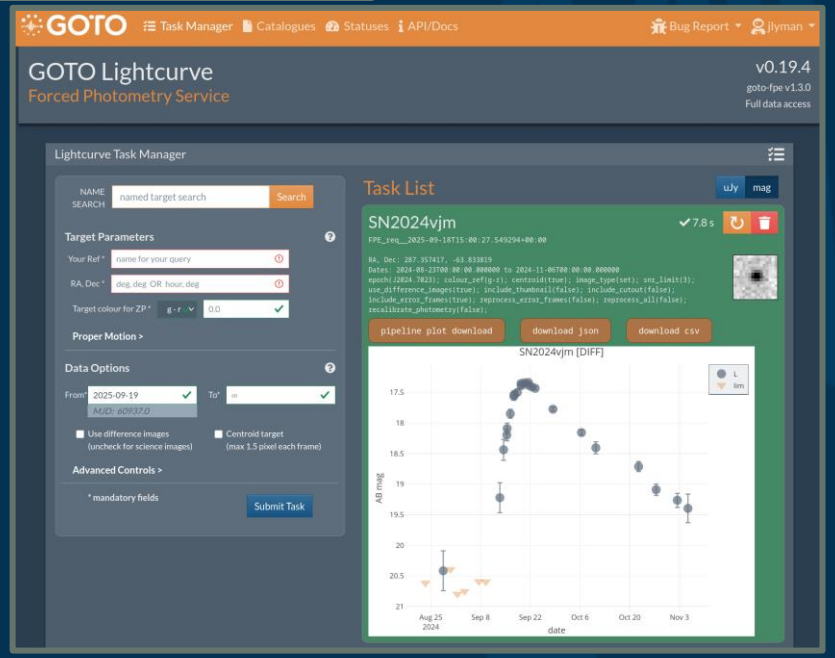
Custom sub-sky surveys for specific science cases

- **~0.3 night extragalactic equatorial survey** for infant transients
- **Galactic plane stares** for rapid variability



Easier access to data products

- **Forced photometry API** (Jarvis et al. in prep)
- **Kafka producer** of GOTO DIA alerts



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