4 April 2022

Supernova Neutrinos in the Multimessenger Era

ELECTROMAGNETIC FOLLOW-UP OF SNE AND THE GRAVITATIONAL WAVE OPTICAL TRANSIENT OBSERVER

Joe Lyman, University of Warwick

UKRI Future Leaders Fellow

WARWICK
THE UNIVERSITY OF WARWICK

UK Research and Innovation

GOTO
GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER

ELECTROMAGNETIC DISCOVERY OF SNE

Joe Lyman – KCL – SN neutrinos – Apr 2022

ELECTROMAGNETIC DISCOVERY OF SNE

SPOT THE DIFFERENCE

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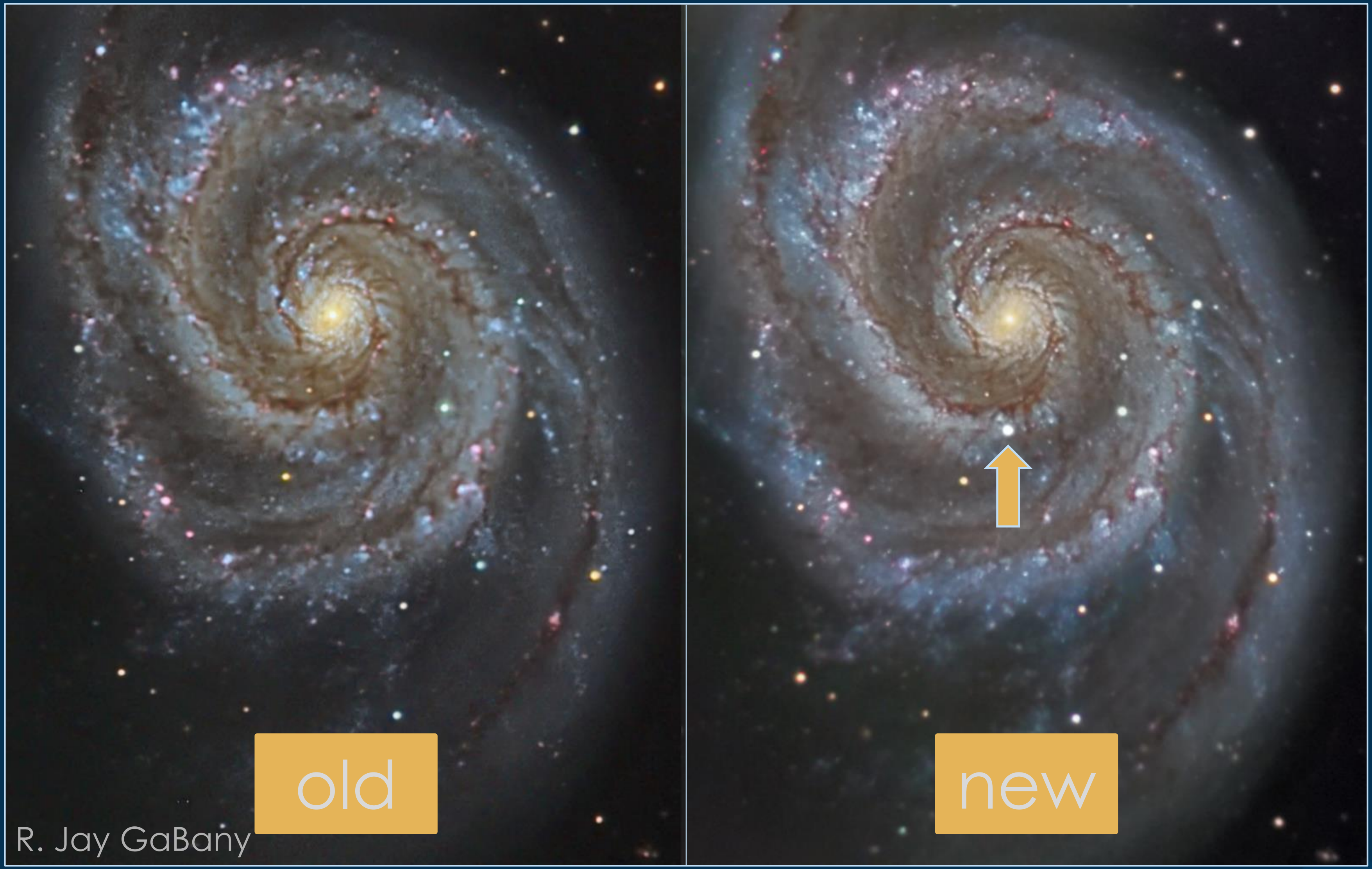
SPOT THE DIFFERENCE



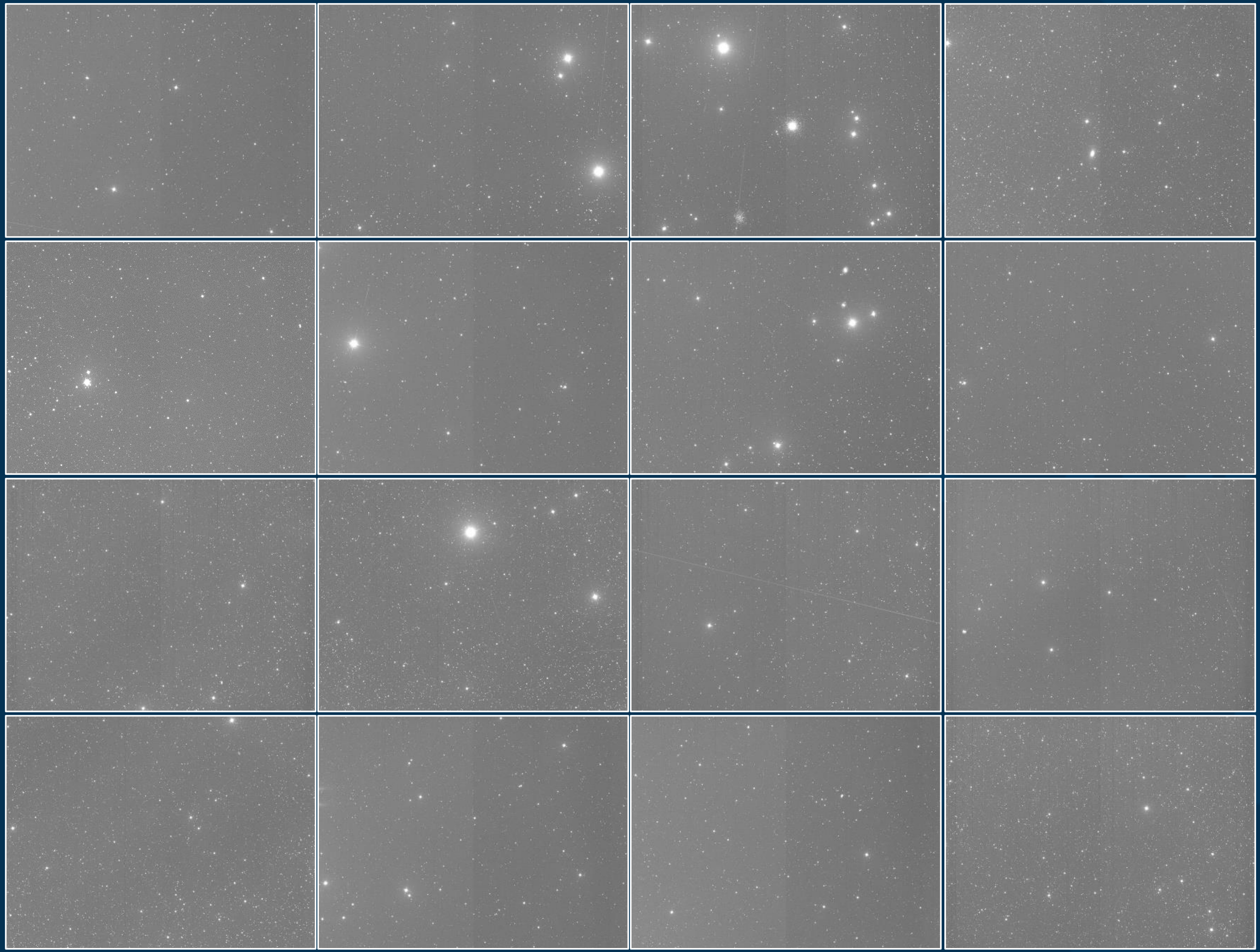
ELECTROMAGNETIC DISCOVERY OF SNE

DATA SCALES

Full moon: 

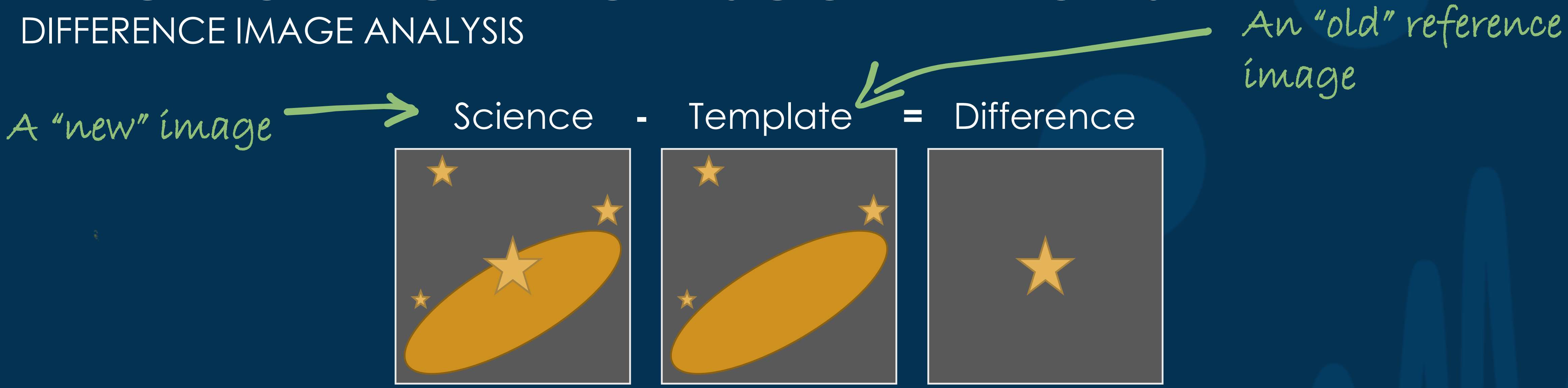
Previous Galaxy: 

GOTO field of view:



ELECTROMAGNETIC DISCOVERY OF SNE

DIFFERENCE IMAGE ANALYSIS



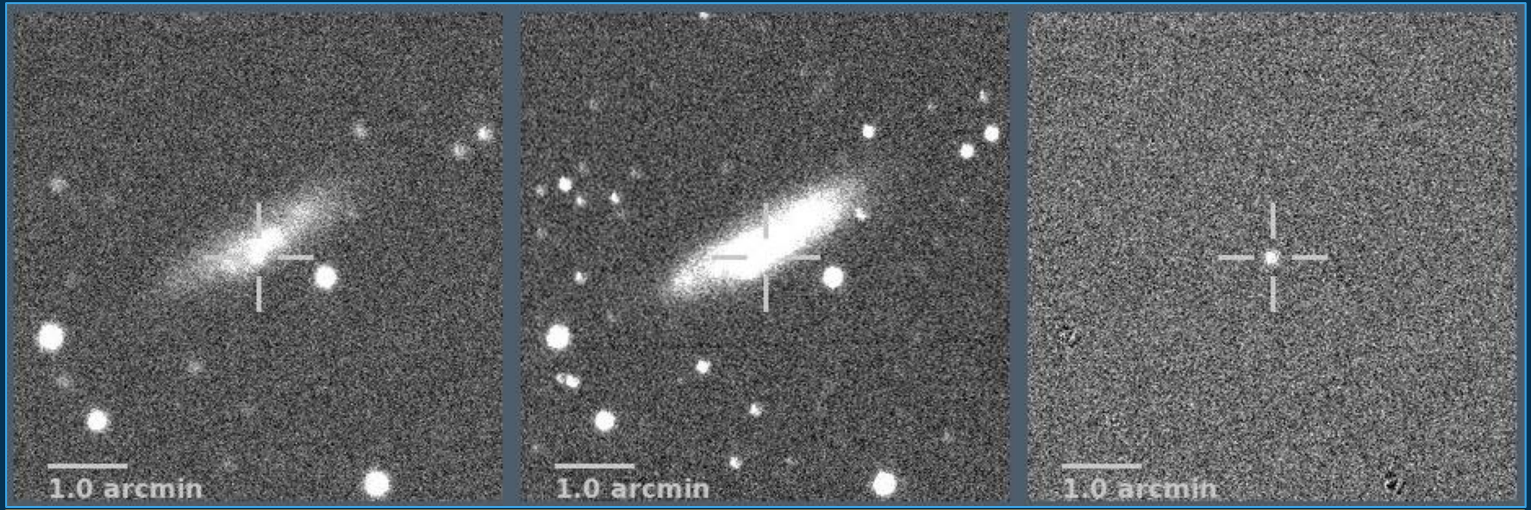
ELECTROMAGNETIC DISCOVERY OF SNE

DIFFERENCE IMAGE ANALYSIS

A "new" image

An "old" reference image

Science - Template = Difference



new – old = difference

MULTI-MESSENGER CONSIDERATIONS

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BRIGHTNESS!

SN 2014J @ 3.5 Mpc

> *The SN is also prominent on R-band photometry from the P48 prior to January 21 […] but remained undetected by our automated software due to pixel saturation.*
>
> Goobar+ 2014

MULTI-MESSENGER CONSIDERATIONS

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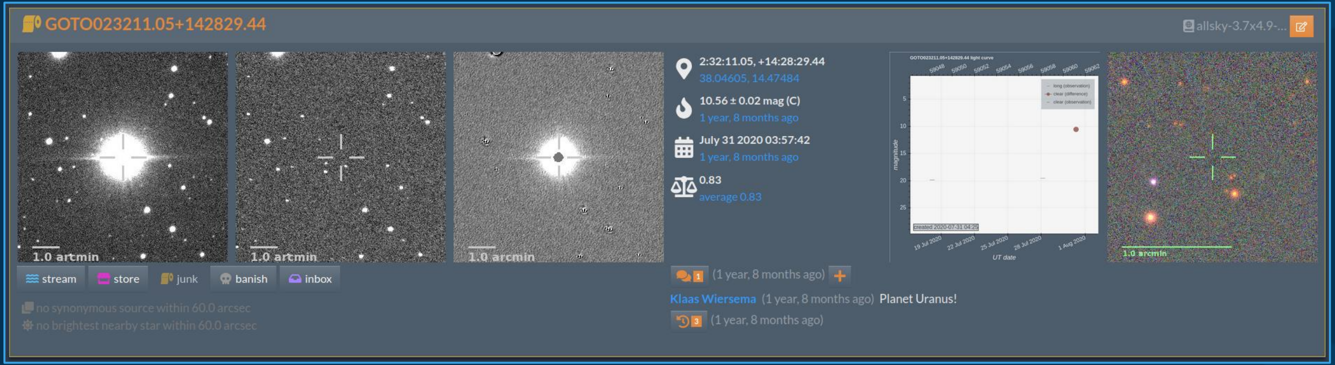
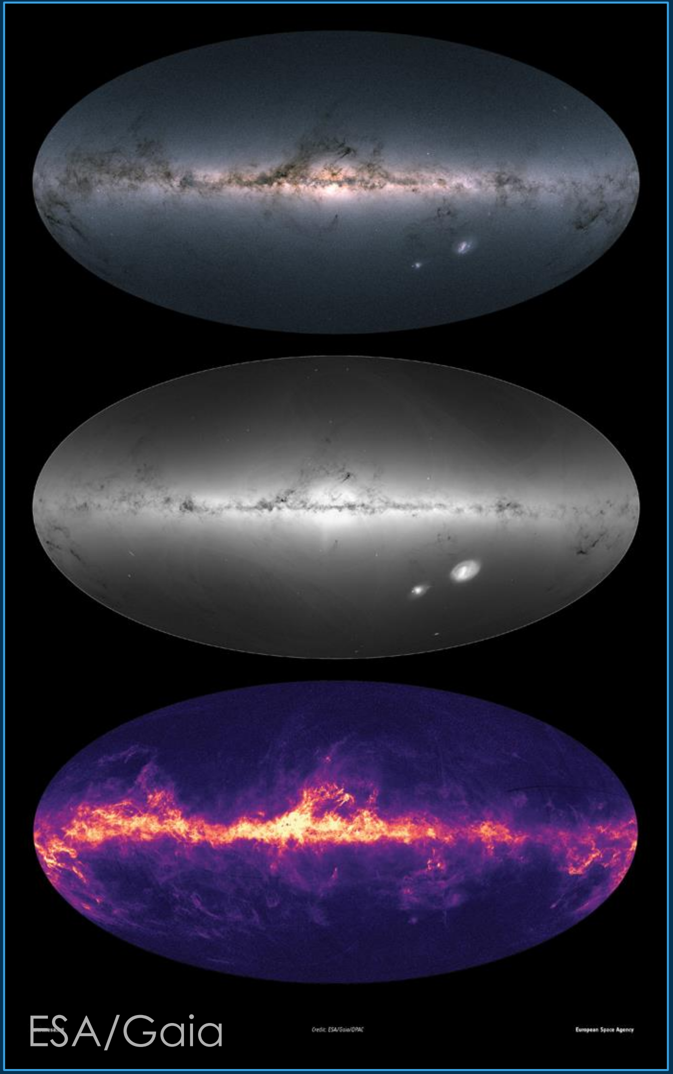


Killestein, JL+ 2021

MULTI-MESSENGER CONSIDERATIONS

MILKY WAY EXTINCTION AND CROWDEDNESS

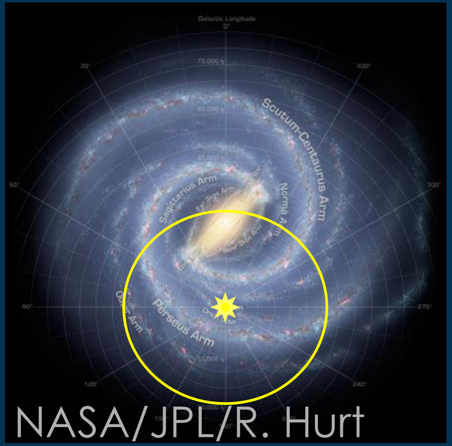
Property	Map	Effect
Brightness of stars		Difficulty finding/extracting SN in difference image
Density of stars		Difficulty finding/extracting SN in difference image
Attenuation of light (extinction)		Fainter and Redder SN



MULTI-MESSENGER CONSIDERATIONS

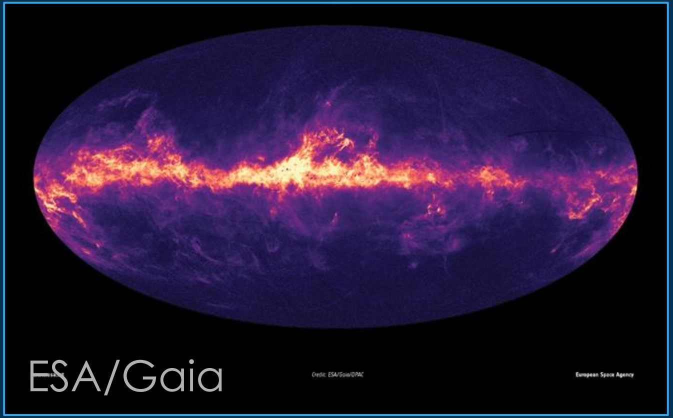
MILKY WAY EXTINCTION AND CROWDEDNESS

An example SN @ 8.5 kpc



	~No extinction (Av ~ 0 mag)	Low extinction (Av < 10 mag)	Moderate extinction (15 < Av < 25 mag)	High extinction (Av > 30)
Optical (~550nm)	-2.5 mag	< 7.5 mag	Between 12-22 mag	> 27.5 mag
Near-infrared (~1200nm)	-2.5 mag	0.5 mag	Between 2-5 mag	> 6.5mag

Attenuation of light (extinction)



Fainter and Redder SN

MULTI-MESSENGER CONSIDERATIONS

MILKY WAY EXTINCTION AND CROWDEDNESS

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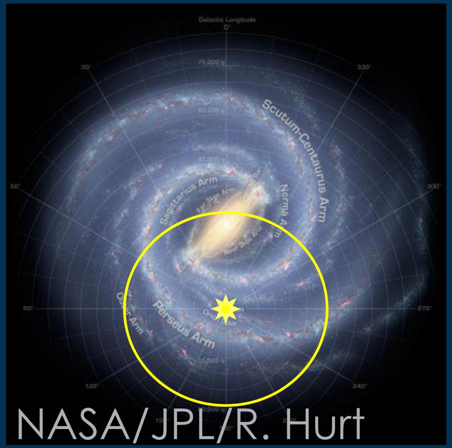

NASA/JPL/R. Hurt

"naked eye"/amateur astronomers

Barely observable with Hubble

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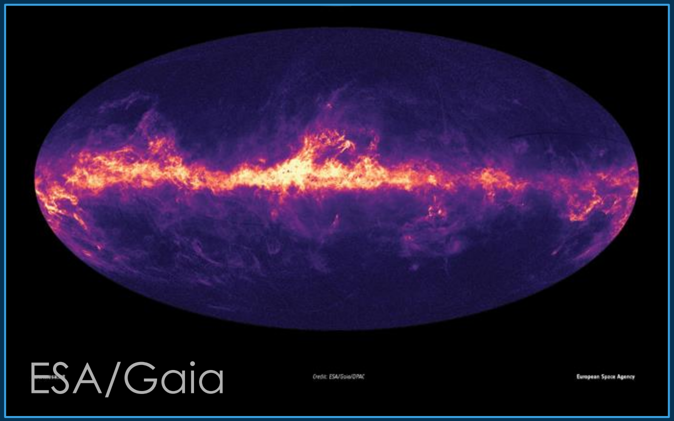
Saturate most professional instruments

Wide-field sky surveys

Attenuation of light (extinction)


ESA/Gaia

Fainter and Redder SN

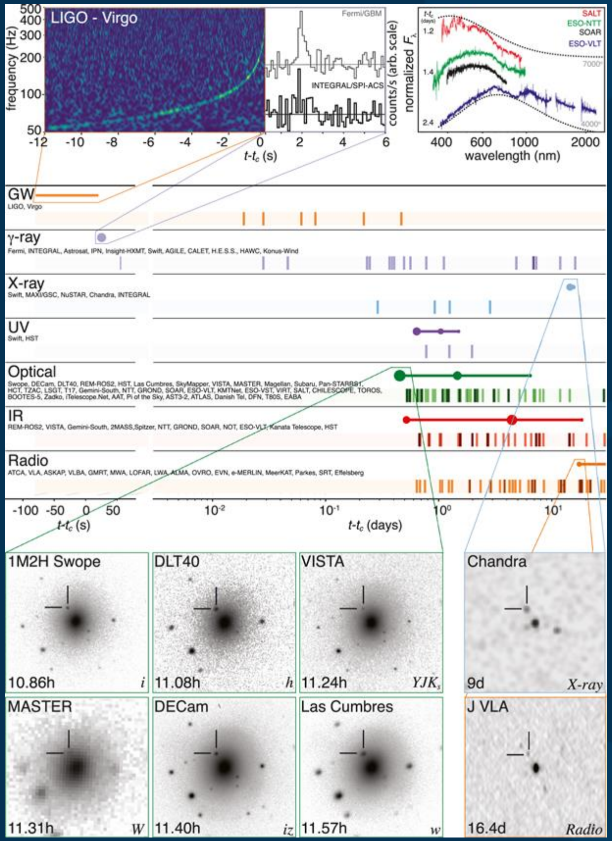
ELECTROMAGNETIC CAPABILITIES

THE EM COMMUNITY'S RESPONSE TO TRIGGERS

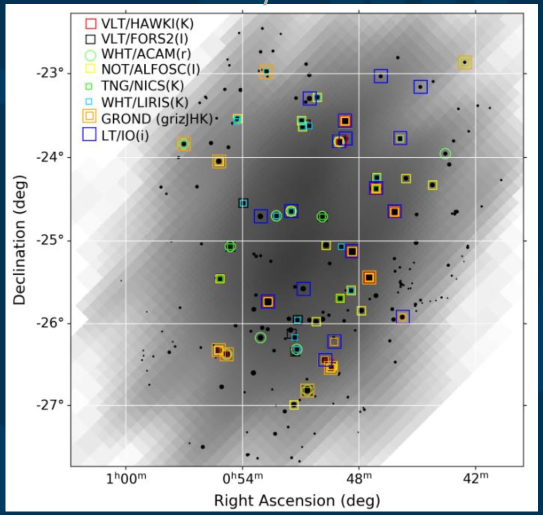
CUES FROM EXISTING ALERTS

- Huge, (somewhat) coordinated effort following Graviational-wave triggers (esp. GW170817)
    - Even in the absence of pre-allocated time on many facilities
- **Provided the confidence is given with a trigger**, most EM facilities are comfortable receiving marginal alerts
    - e.g. IceCube Neutrino alerts.

GW170817 (Abbott+ 2017)



GW190814 (ENGRAVE collab 2020)



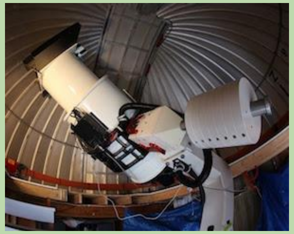
ESA/Gaia

EM DISCOVERY FACILITIES

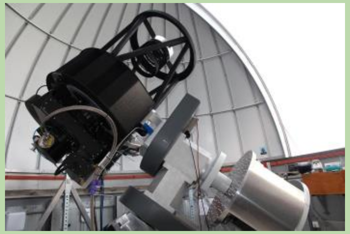
WIDE-FIELD SKY SURVEYS

ASAS-SN

atlas



BlackGEM

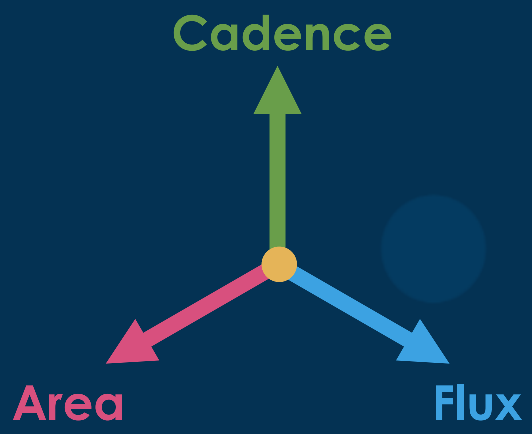


GOTO
GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER

ZTF

Gattini-IR

- **Field of views 10s of sq. degree**
  - ~1-10s of unit telescopes
- **Optical [NIR] depths of 18-23 [16] mag**
  - ~0.1-1m apertures
- **Saturation around 9-12 mag**
- **Cadence of 1-few days**
  - Sky coverage 1000s sq. degree/night



EM FOLLOW-UP POTENTIAL

SPECIALISED INSTRUMENTATION

High spatial resolution

- Effective resolution of 3.8e14 cm (less than Neptune's orbit) at 8.5 kpc
- Resolved observations in 4-5days assuming 10,000km/s expansion

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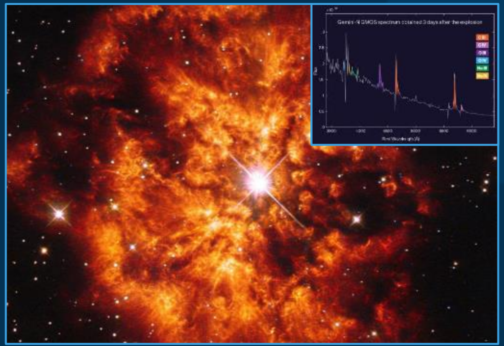

HST / Gal-Yam+ 2022

- Probe immediate surroundings and mass loss of progenitor star
- Spectropolarimetric observations probe asymmetry of elemental- and bulk-ejecta

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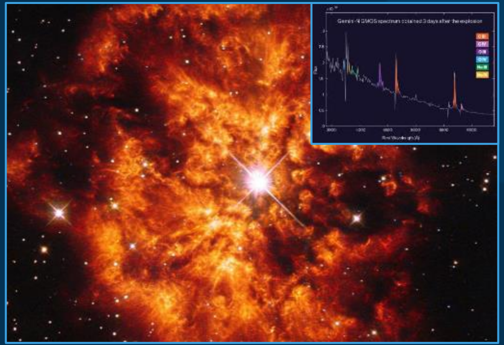

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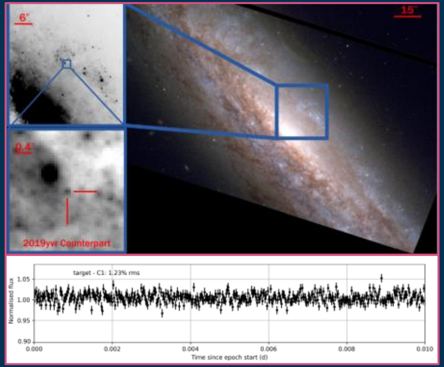

- Pre-explosion variability probes final stages of stellar evolution
- Post-explosion short-timescale variability probes circum-stellar medium inhomogeneities

Kilpatrick+ 2021/ Killestein+ in prep

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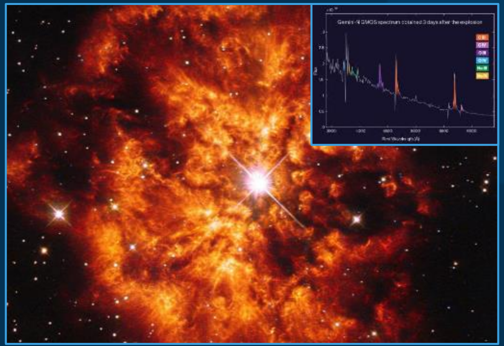

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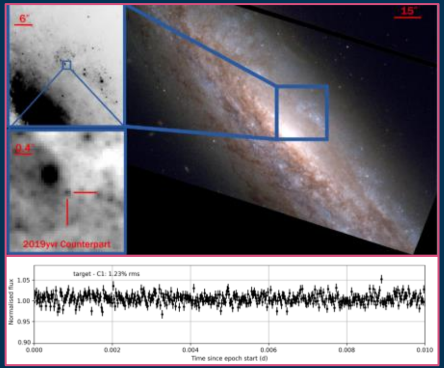

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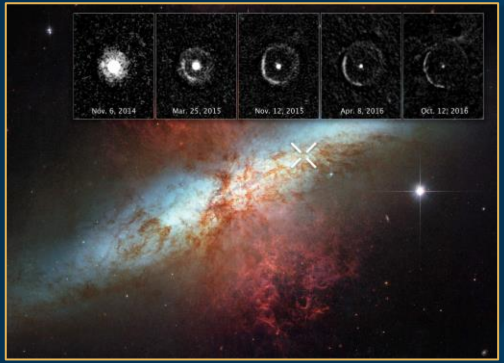
Kilpatrick+ 2021/ Killestein+ in prep

Late-time light echoes



HST / Y. Yang+ 2015

- Map the spatial/density distribution of the interstellar medium
- Obtain different viewing angles of the supernova

GOTO

GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER

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THE UNIVERSITY OF WARWICK

MONASH University

MANCHESTER 1824
The University of Manchester

The University Of Sheffield.

UNIVERSITY OF TURKU

NARIT

UNIVERSITY OF LEICESTER

INSTITUTO DE ASTROFISICA DE CANARIAS · IAC ·

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EXPLORING THE COSMOS SINCE 1790

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EM MULTI-MESSENGER ASTRONOMY

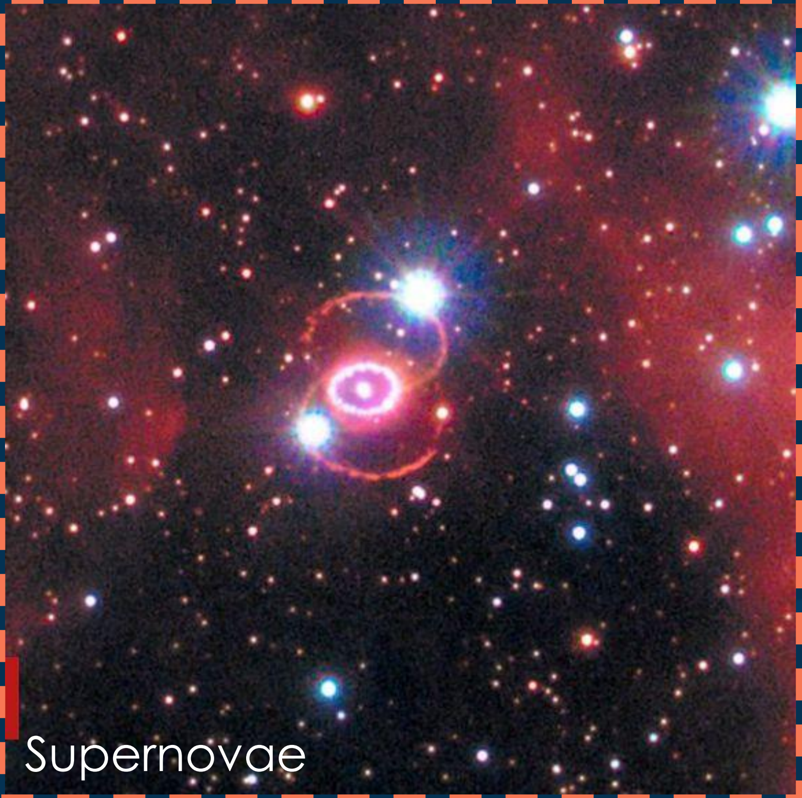
SOURCES

Cosmic rays

Neutrinos

Gravitational waves

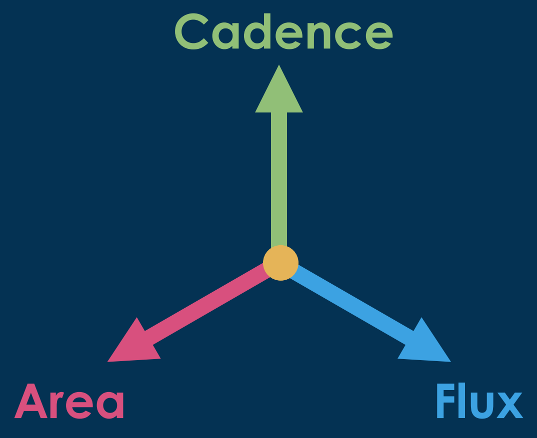
Electromagnetic



GOTO DESIGN AND PURPOSE

GOTO
GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER

- A dedicated wide-field optical survey for detecting EM counterparts of GW sources
- Use small unit telescopes in arrays to create cost-effective, scalable, and adaptable wide-field survey



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GOTO PROTOTYPE SYSTEM (2017-2020)

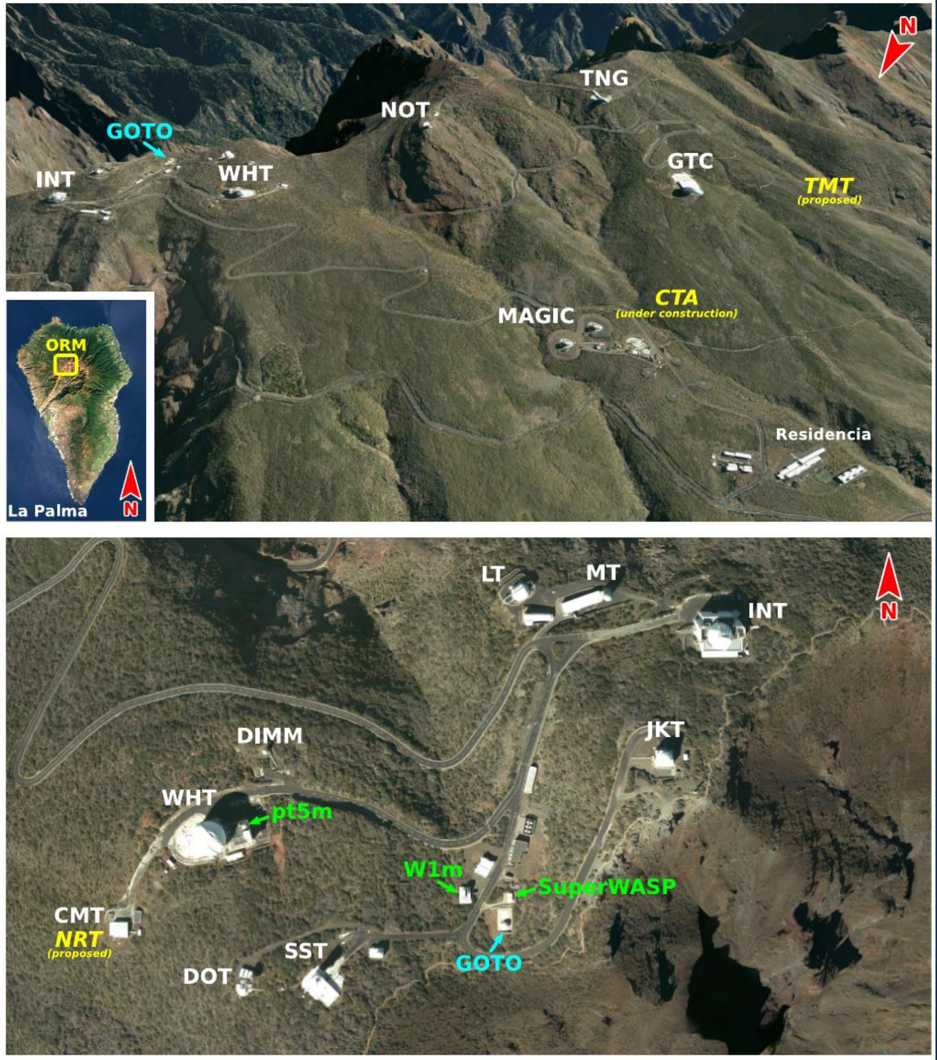
Steeghs+ 2022

GOTO
GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER

La Palma

- 4x40cm f/2.5 unit telescopes

La Palma 4 UT prototype in 2018



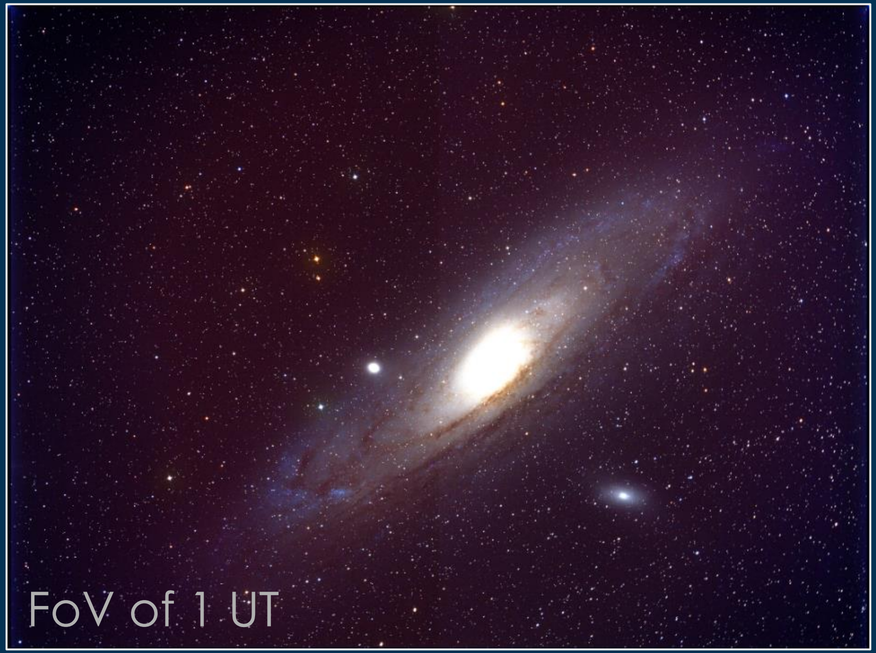
GOTO PROTOTYPE SYSTEM (2017-2020)

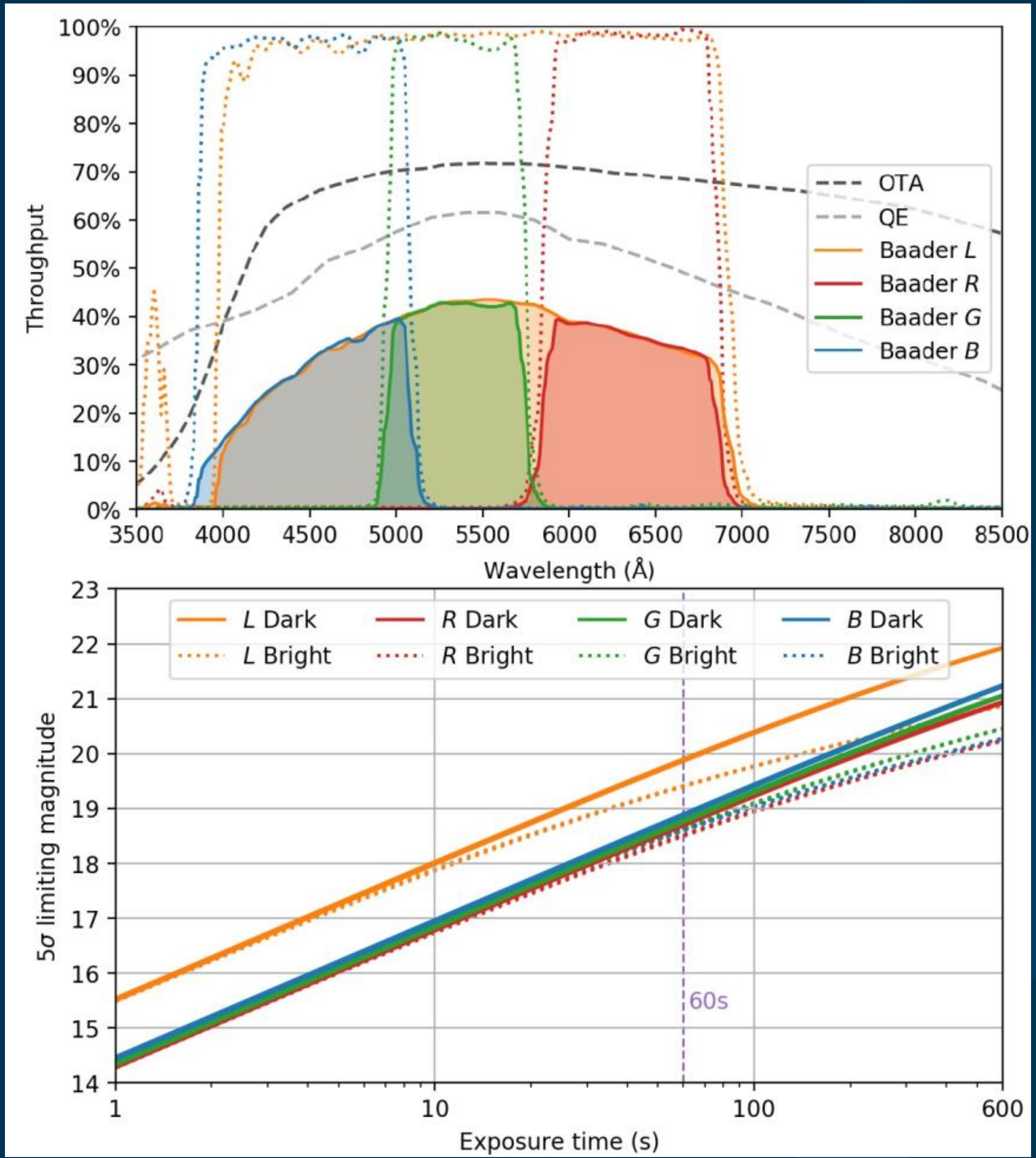
Steeghs+ 2022

GOTO
GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER

La Palma

- 4x40cm f/2.5 unit telescopes
- 1.25"/pixel (50M pixel CCD)
- 5 slot filterwheel (Baader LRGBC)
- Total field of view ~ 20 sq. degree
- ~20 mag in 60s





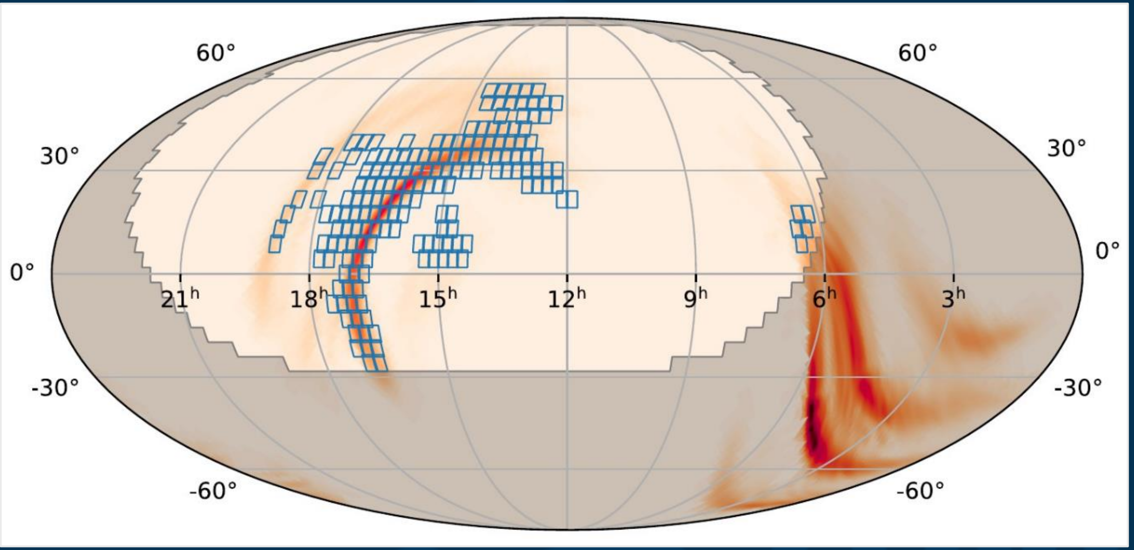
GOTO PROTOTYPE SYSTEM (2017-2020)

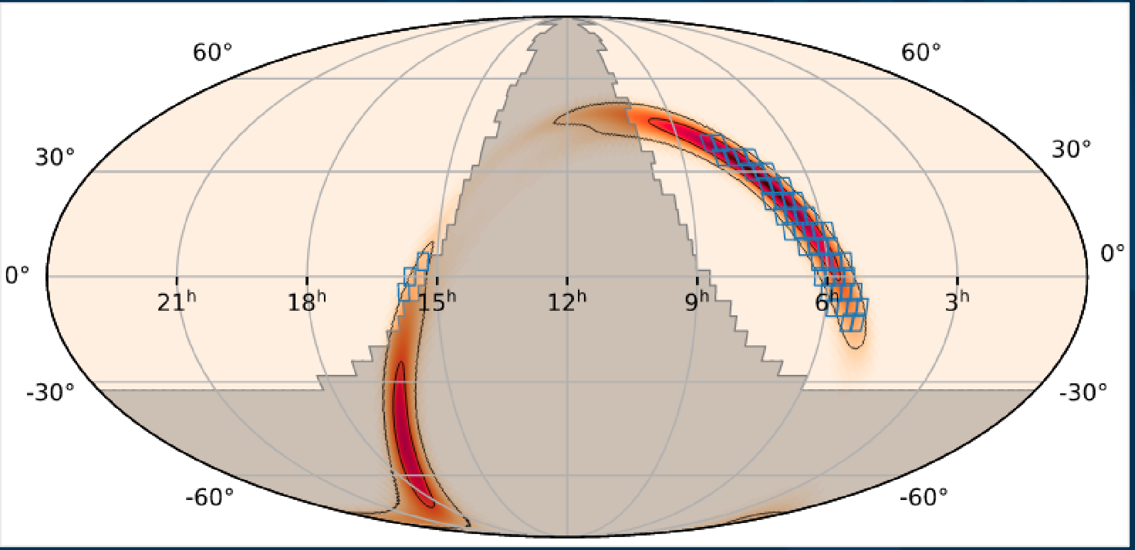
Steeghs+ 2022

GOTO
GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER

- Triggered on 32 GW events in one-half of a LIGO/Virgo observing run
- Reached depths to detect kilonovae comparable to NS-NS GW detector horizons in most cases
- Observing within a few minutes of trigger when observability allowed

Gompertz+ 2020





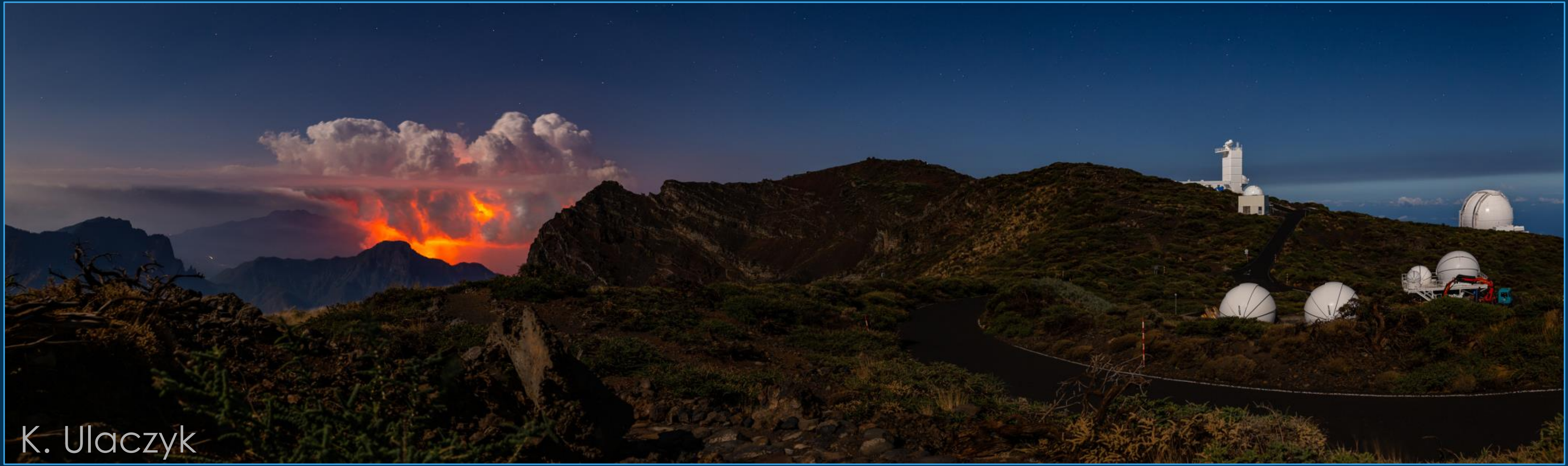
GOTO DEVELOPMENT (2020-2022)

NEW HARDWARE

UKRI Science and Technology Facilities Council

GOTO DEVELOPMENT (2020-2022)

"CHALLENGES"



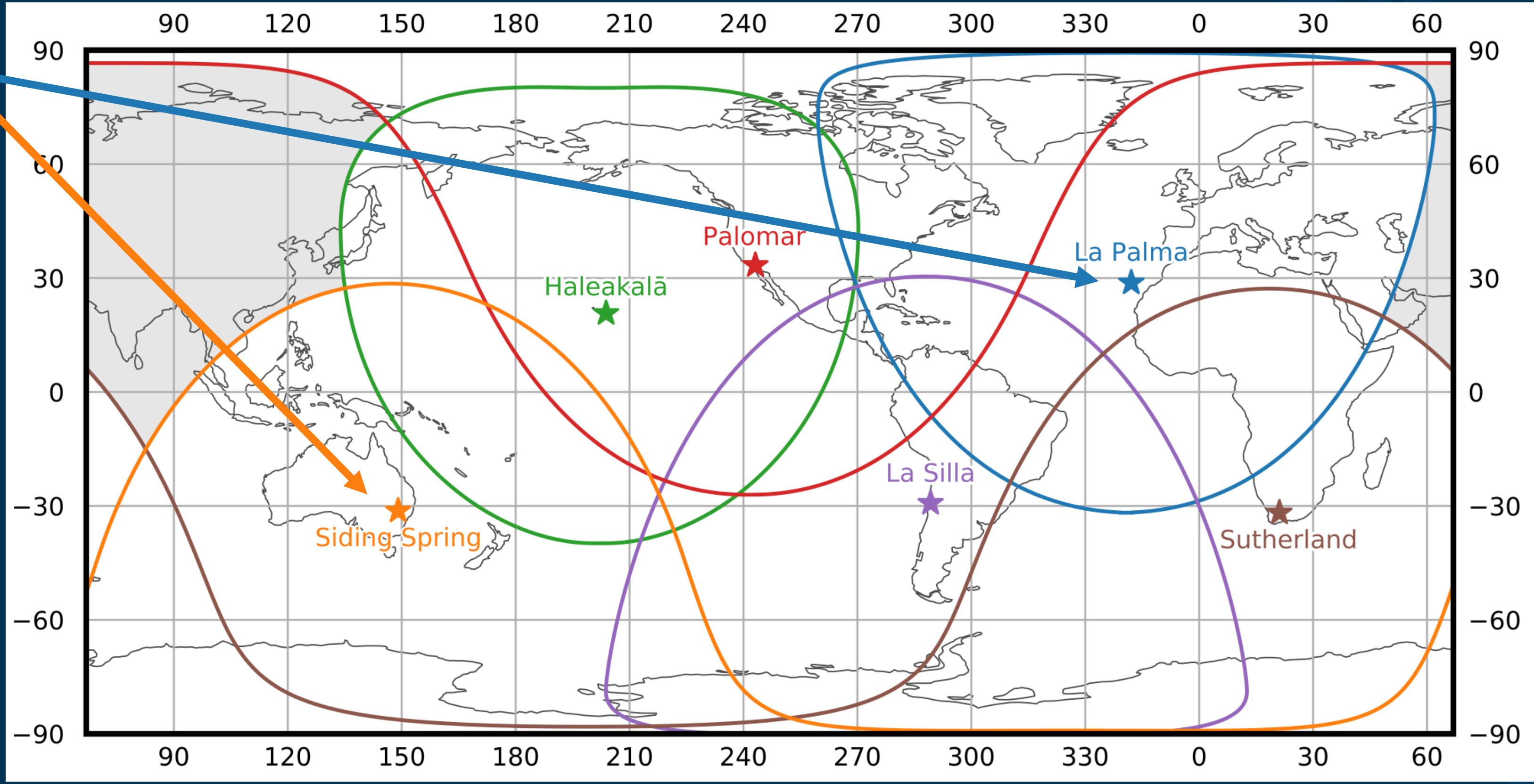
- [x] Pandemic
- [x] Volcano
- [x] Hail/Ice
- [ ] Locusts

GOTO FULL DESIGN
SITES

- **La Palma** node complete with 2x8 UT mounts
- **Siding Spring** node construction imminent

La Palma node in 2022

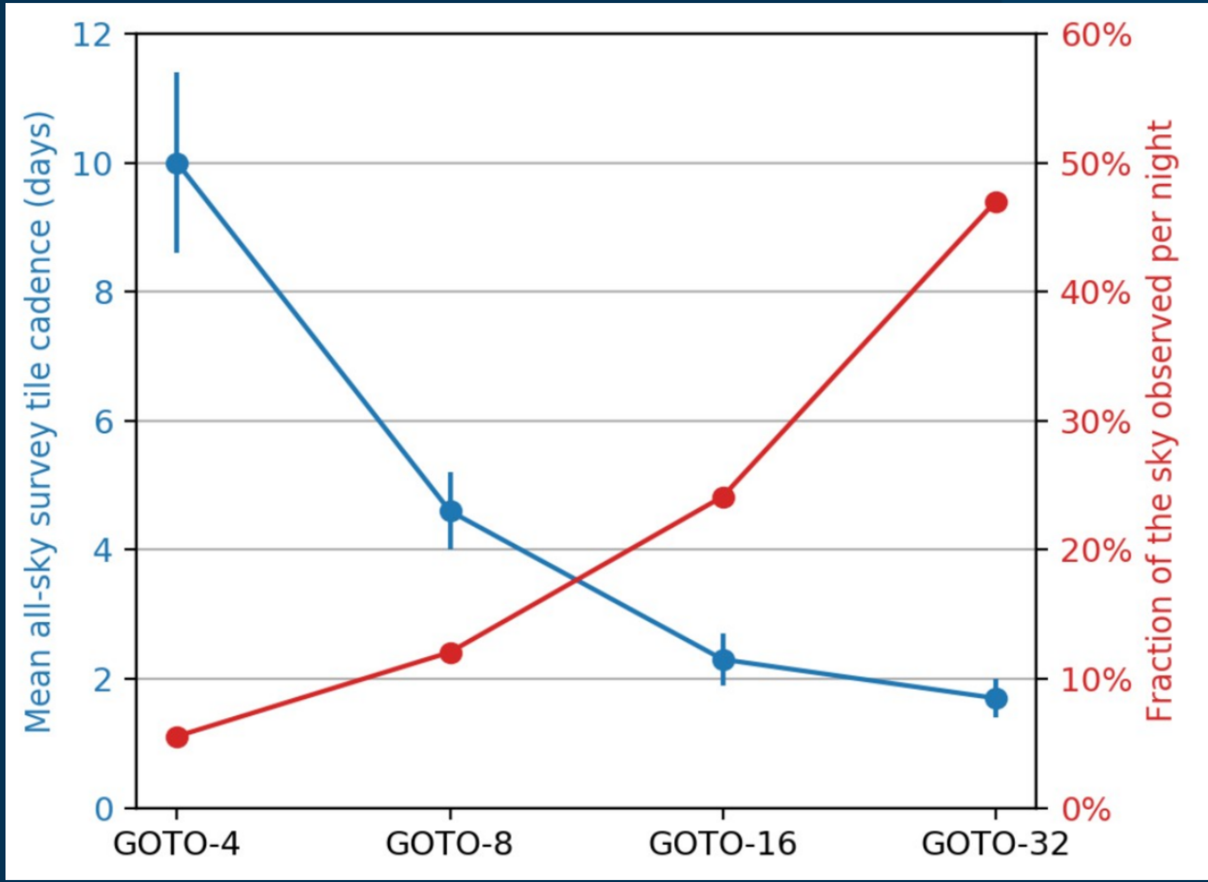
GOTO fills in longitudinal gaps for continuous night-sky coverage



GOTO FULL DESIGN
CADENCE

GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER

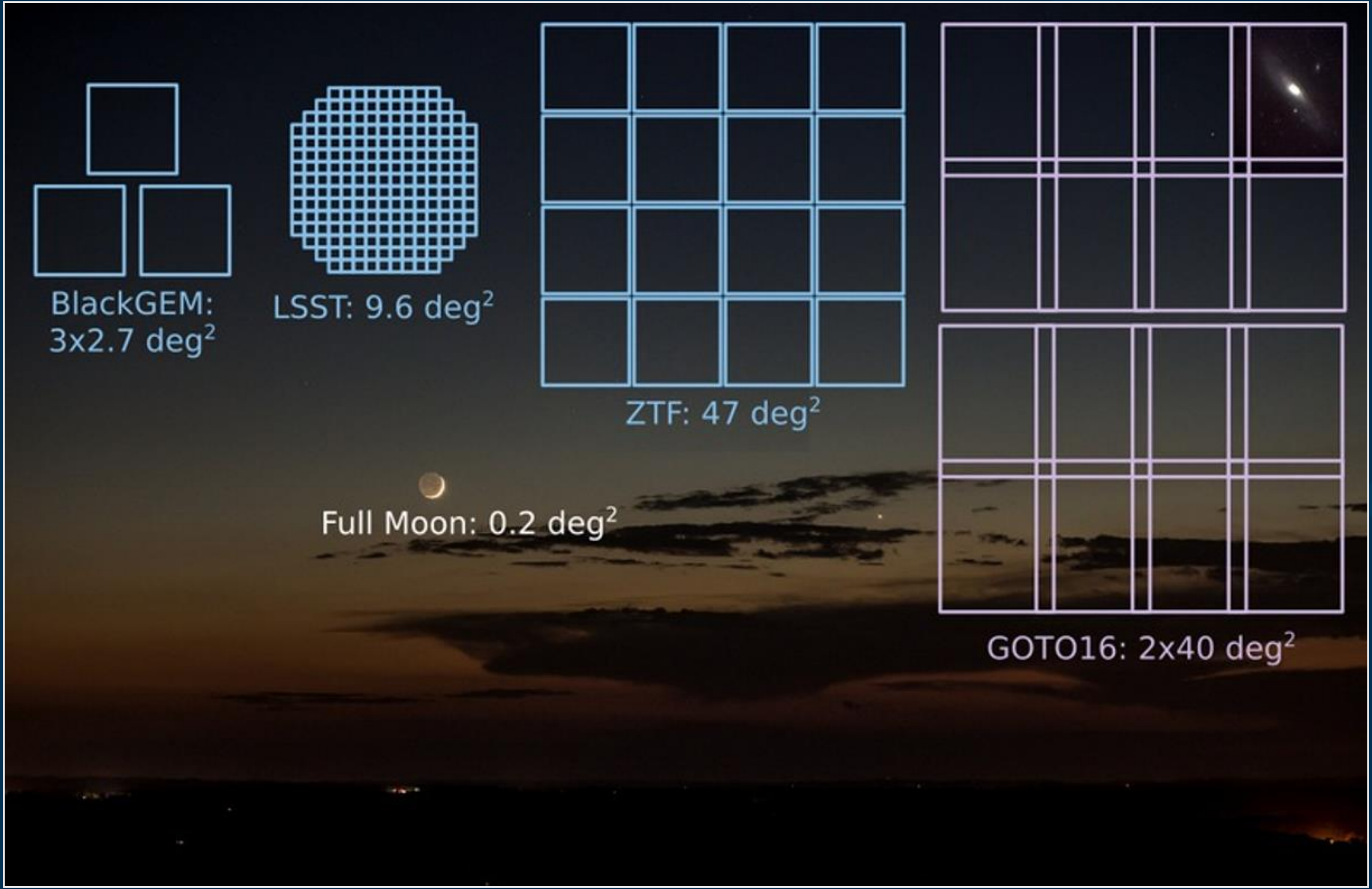
GOTO will survey the entire sky every ~2 days



GOTO FULL DESIGN

FIELD OF VIEW

Each GOTO node will have a ~80 deg² footprint



GOTO

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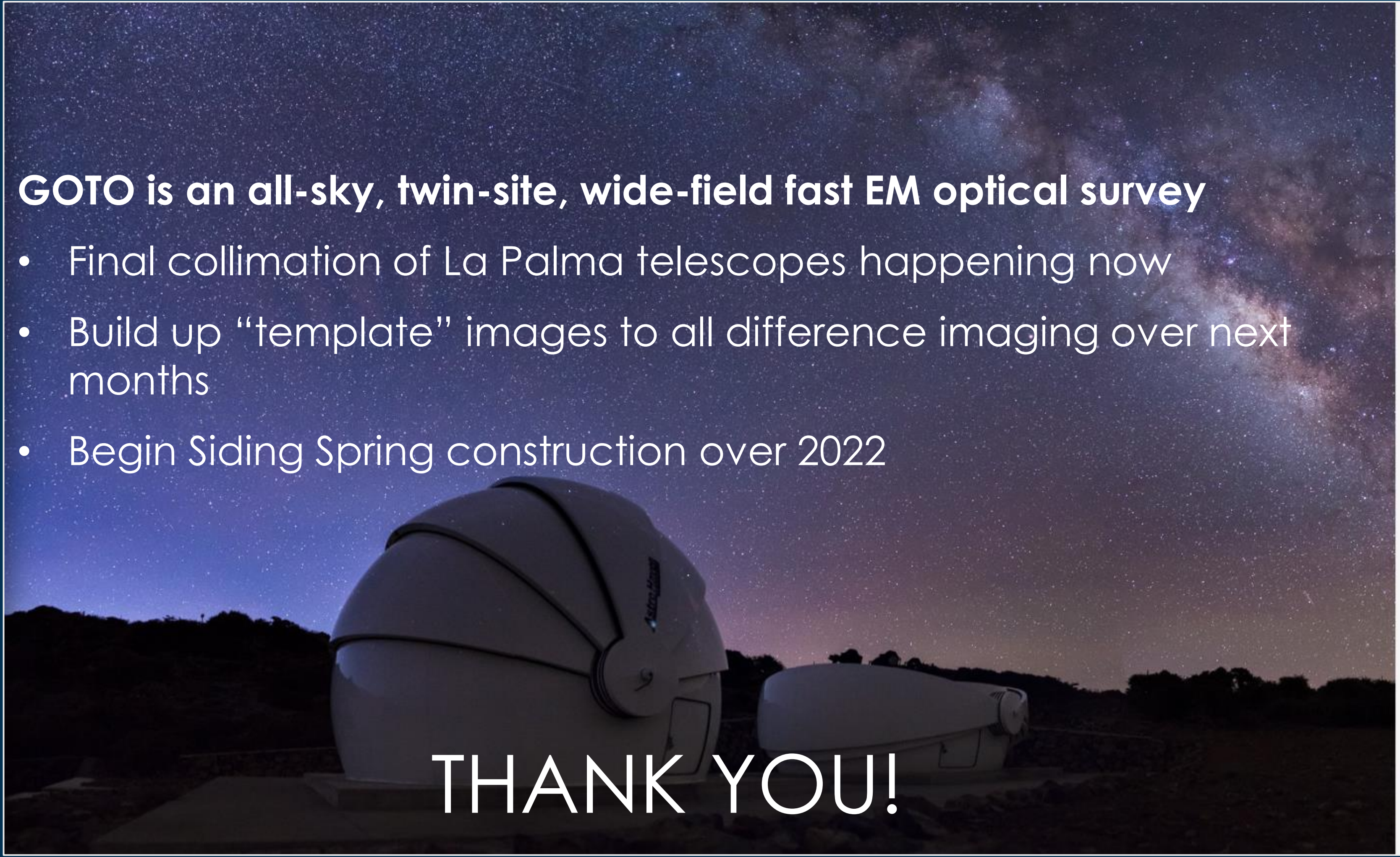

GOTO is an all-sky, twin-site, wide-field fast EM optical survey

- Final collimation of La Palma telescopes happening now
- Build up “template” images to all difference imaging over next months
- Begin Siding Spring construction over 2022

THANK YOU!

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GOTO

GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER

- Multi-messenger astronomy offers new means to study exotic transients
- Gravitational-wave EM follow-up is key in next detector runs (2022-2023) to build on the legacy of GW170817
- GOTO is a UK-led project dedicated to multi-messenger science
- GOTO's full design is an all-sky, twin-site, wide-field fast optical survey
  - La Palma science operations imminent
  - Siding Spring to be completed over 2022
- GOTO will provide a stream of new discoveries and rapid follow-up, enabled by novel automated classification models

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