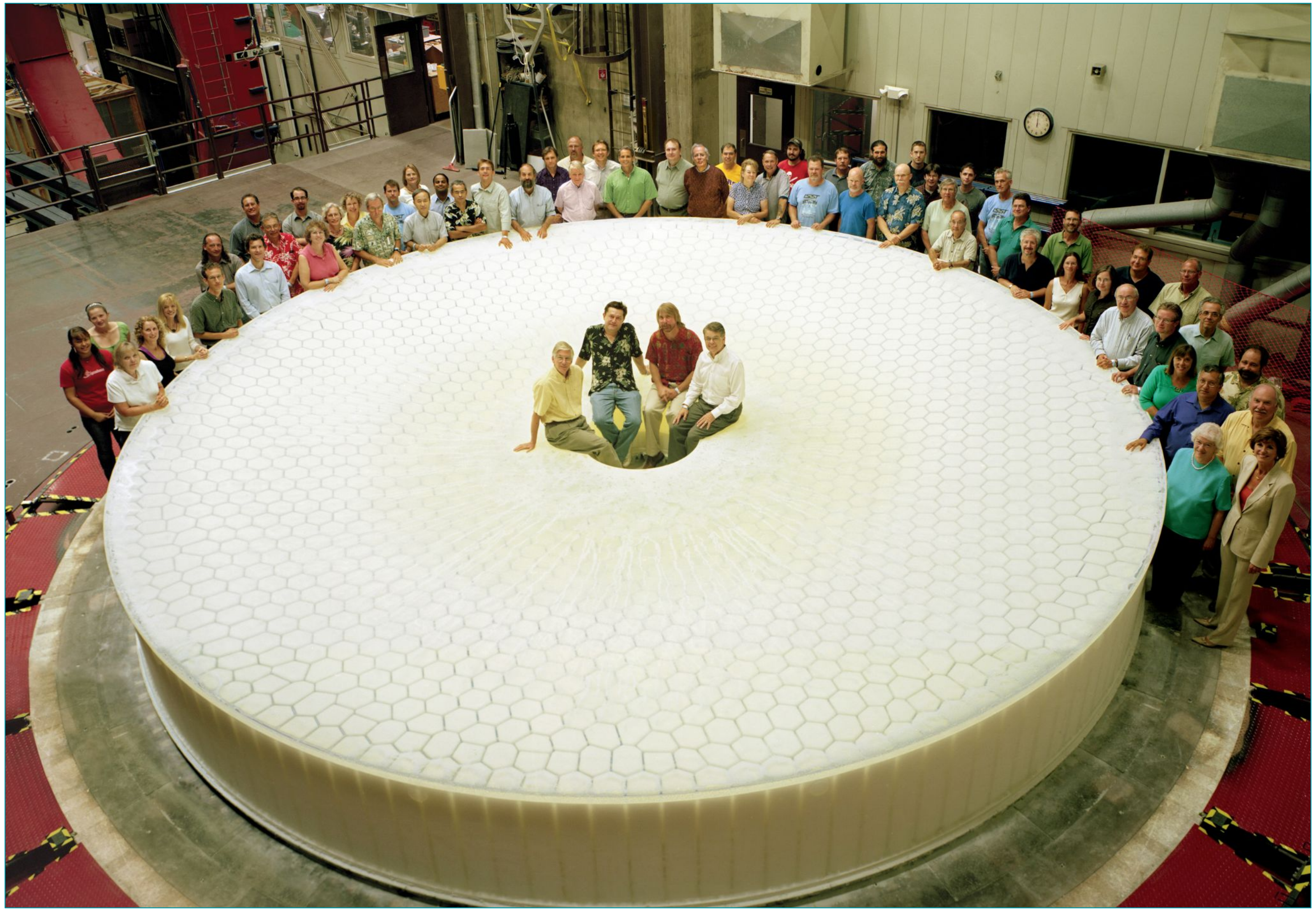
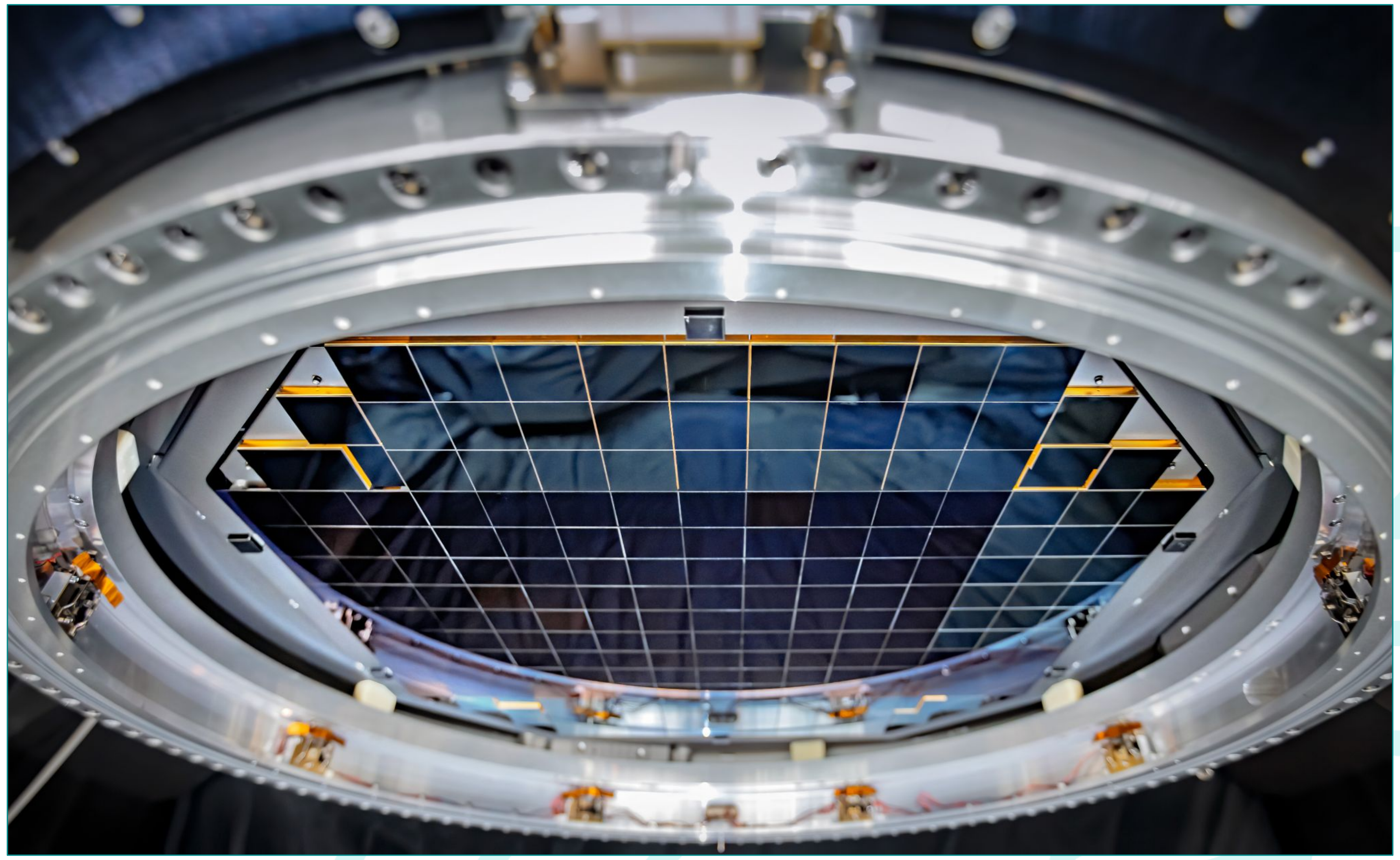
Multi-Messenger Astronomy with Rubin Observatory

Eric Bellm
Alert Production Science Lead

ASTR 597A | 2 March 2023

The Vera C. Rubin Observatory is a powerful new survey being built now in Chile.





9.6 square degree field of view

6.67 m effective aperture

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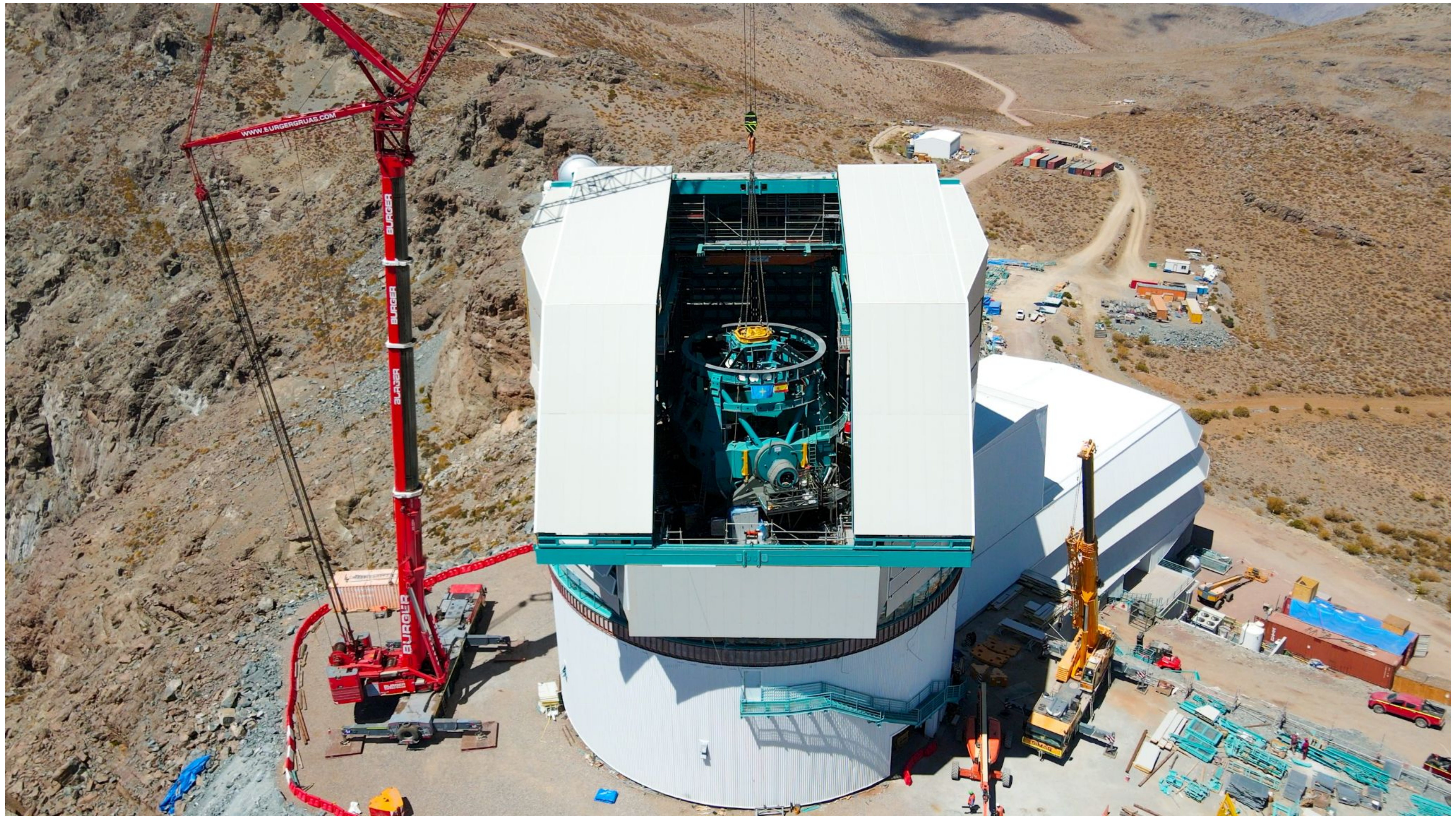
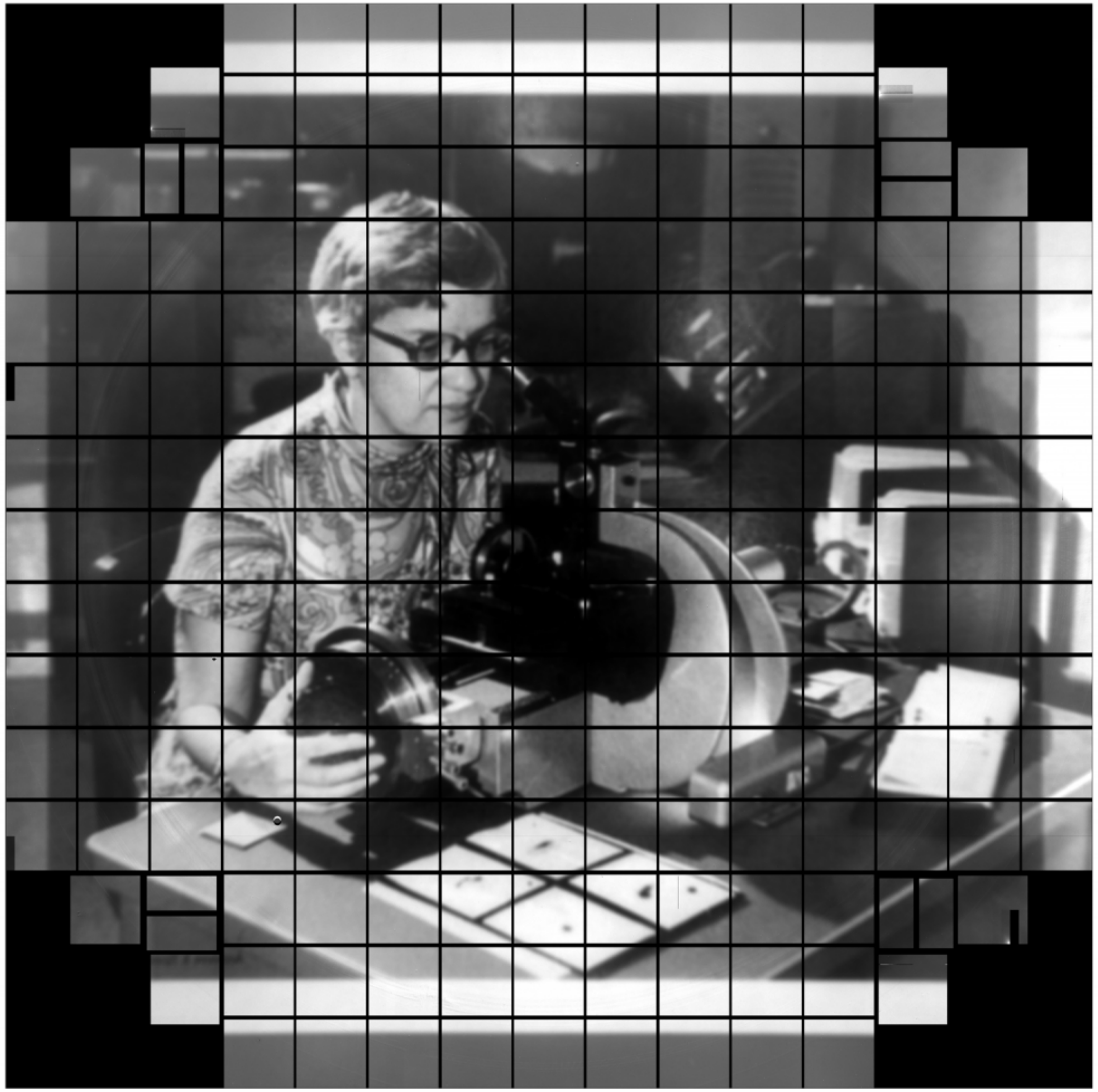
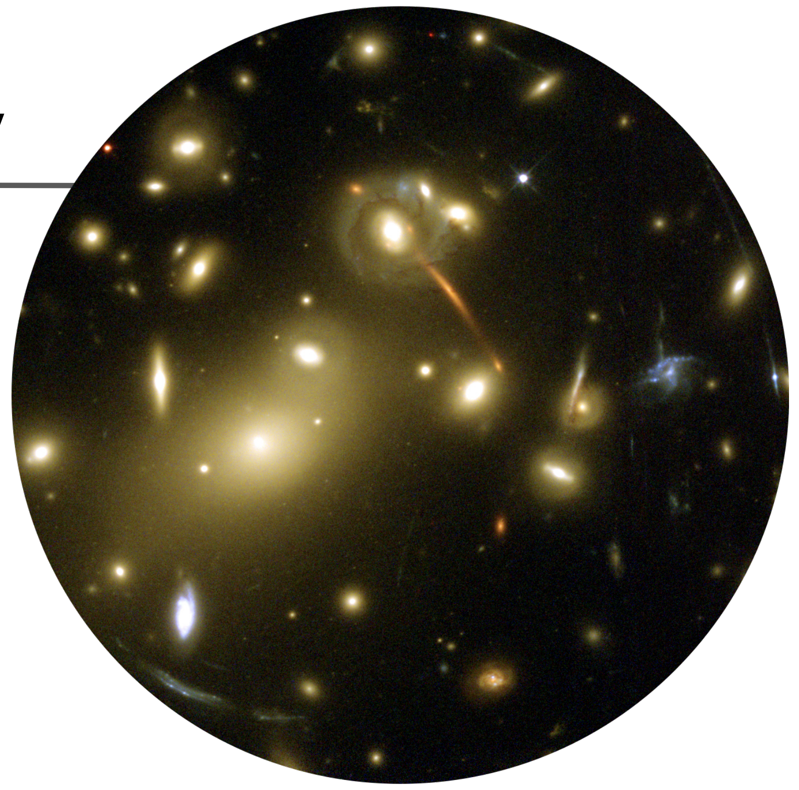


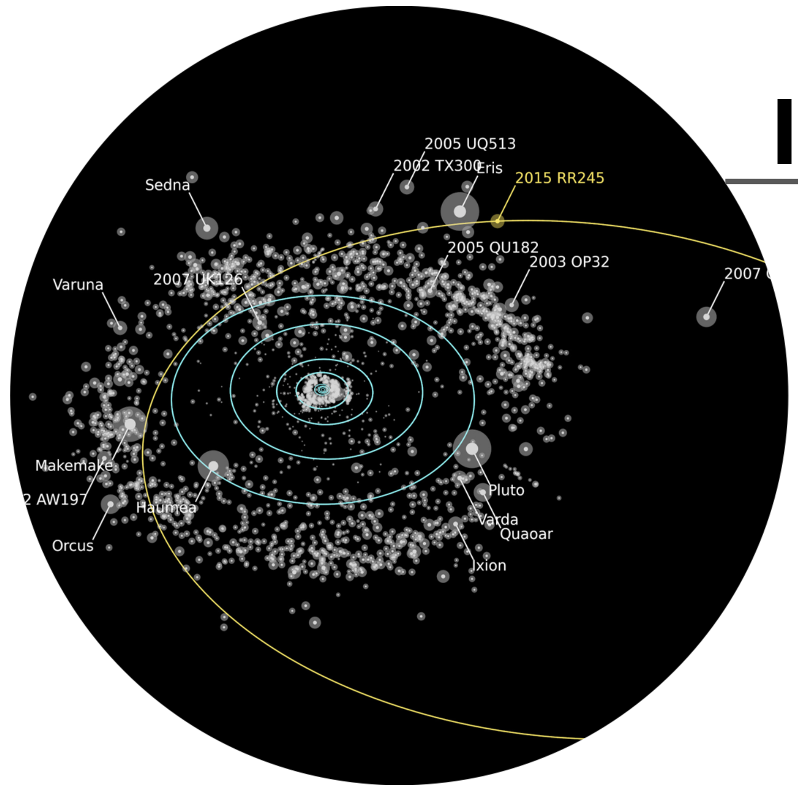


Key Science Drivers

Probing Dark Matter & Dark Energy

- Strong & Weak Lensing
- Large Scale Structure
- Galaxy Clusters, Supernovae



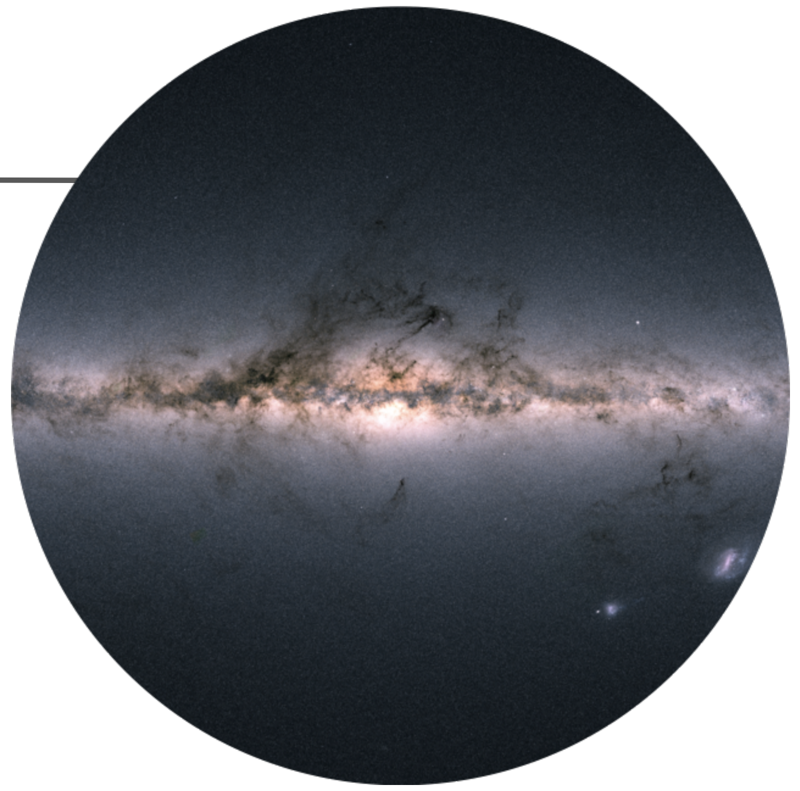


Inventory of the Solar System

- Comprehensive small body census
- Comets & ISOs
- Planetary defense

Mapping the Milky Way

- Structure and evolutionary history
- Spatial maps of stellar characteristics
- Reach well into the halo



Exploring the Transient Optical Sky

- Variable stars, Supernovae
- Fill in the variability phase-space
- Discovery of new classes of transients

The aim of this class has been to give grads the scientific and technical background to do great LSST science.

ASTR 597A

Search

CONTENTS:

- Enrollment
- Schedule
- Assignments
- Final Project
- The Rubin Science Platform
- Useful Resources

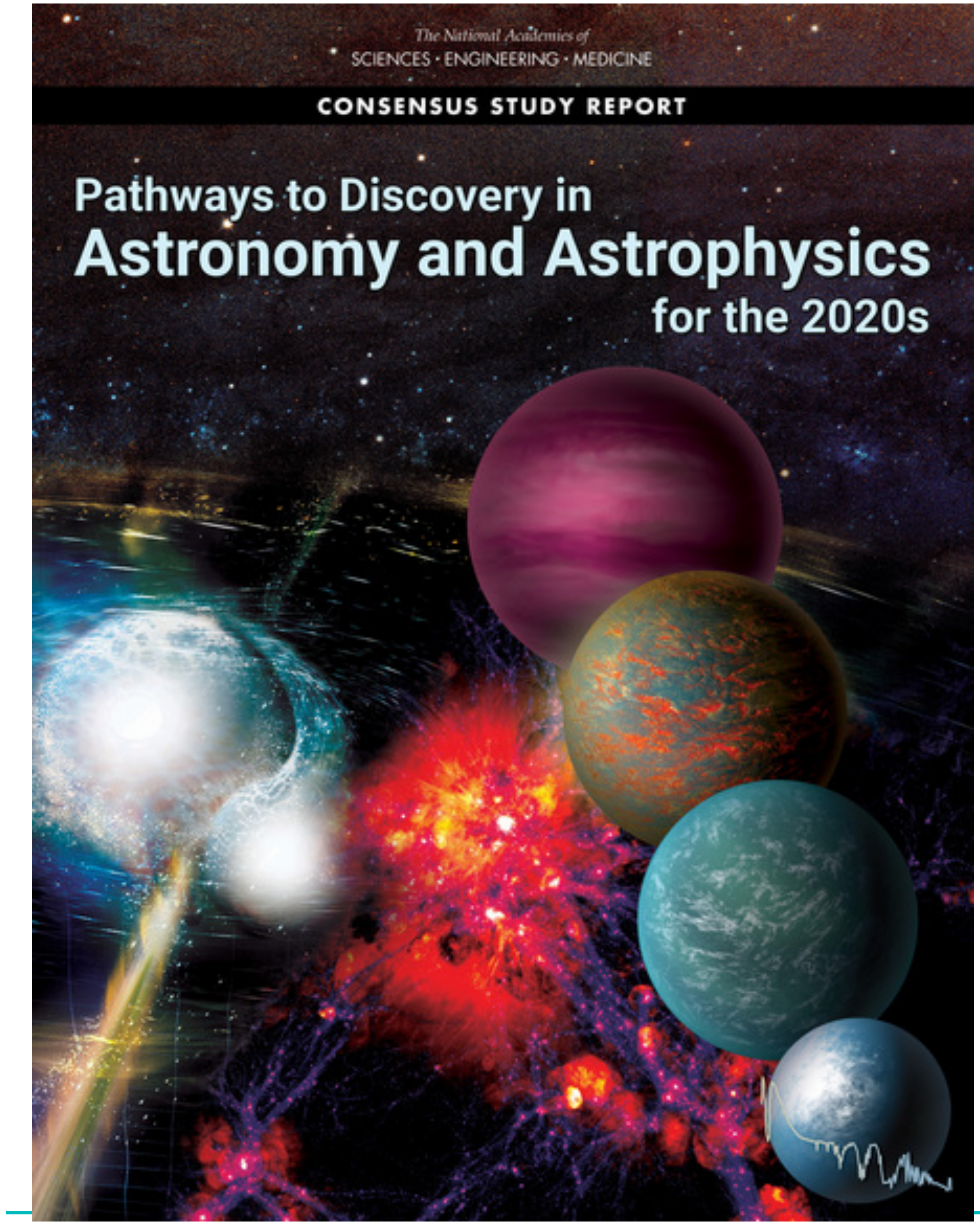
ASTR 597A: Astronomy with Rubin Observatory and LSST

Instructors

Eric Bellm & Zeljko Ivezic with the UW Rubin team

- Week 1: Introduction to LSST and the RSP
- Week 2: Status of the Rubin Construction Project
- Week 3: LSST Data Processing Algorithms and Data Products
- Week 4: Survey Scheduling in Commissioning and Operations
- Week 5: Static Sky Science: Extragalactic, Photo-z, & Cosmology
- Week 6: Solar System Science
- Week 7: Time Domain Science: Transients
- Week 8: Time Domain Science: Variables
- Week 9: Static Sky Science: Galactic Structure
- Week 10: Commissioning Plans & Final Projects

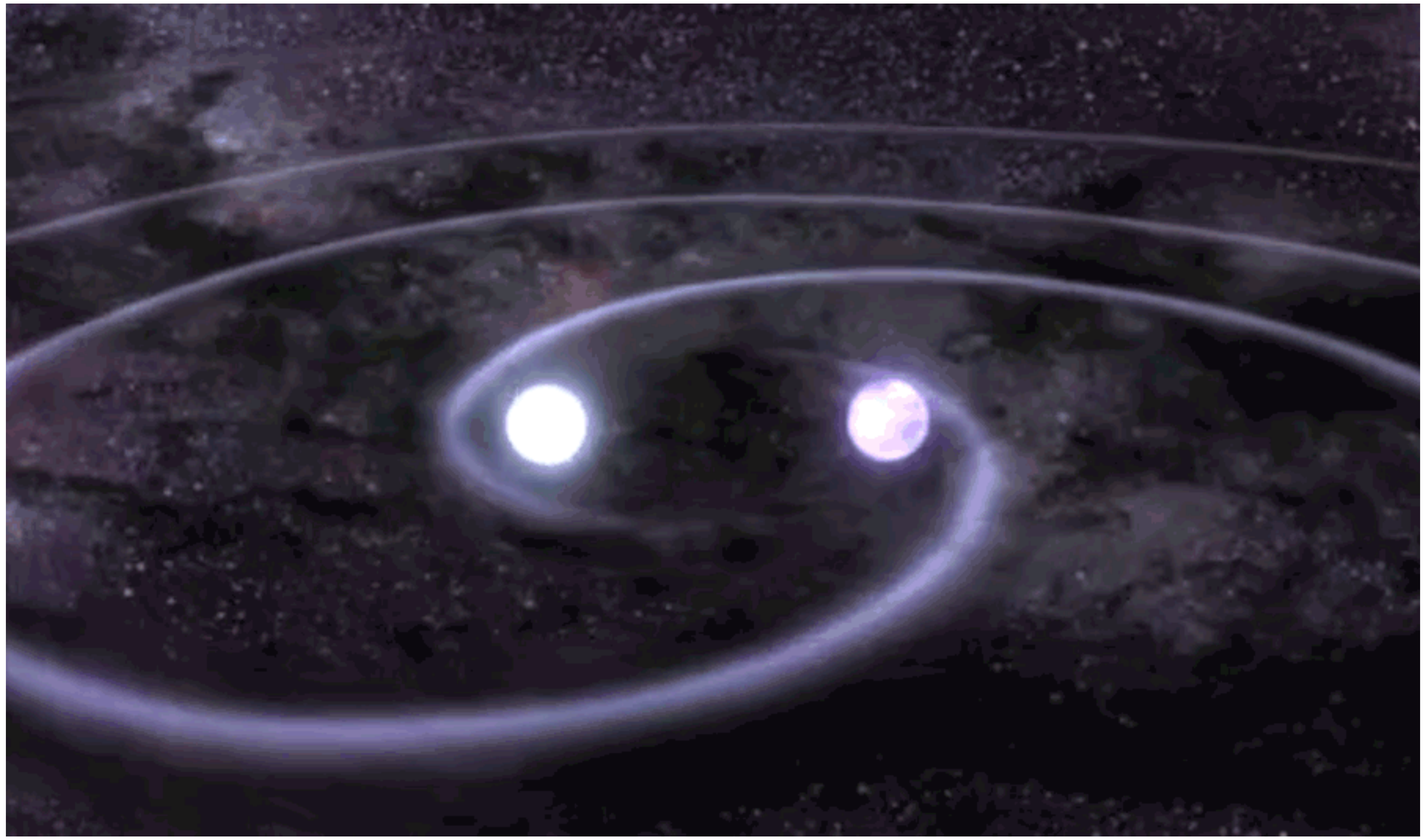
Multi-Messenger Astronomy was identified as a major priority of the 2020 decadal survey.



Priority Area: New Windows on the Dynamic Universe

This report's science theme of *New Messengers and New Physics* captures the broad array of science made possible by observing the sky in new ways. Within this theme, the decadal survey has identified the priority science area of "New Windows on the Dynamic Universe"—the study of neutron stars, white dwarfs, collisions of black holes, and stellar explosions using the complementary perspectives provided by the wide range of messengers from light in all its forms from radio to gamma rays, gravitational waves, neutrinos, and high-energy particles. In parallel to remarkable advances in observations with multiple messengers from the LIGO/Virgo/Kagra gravitational wave and the IceCube high-energy neutrino observatories, the combination of large detectors, big data, and software advances for handling that data continues to transform the previously static view of the sky to one with nearly daily movies. Future upgrades of ground-based gravitational wave facilities, together with the launch of LISA make this a high priority for discovering new physics, and making astronomical measurements that will change paradigms.

Compact object mergers can produce gravitational waves detectable by interferometers.



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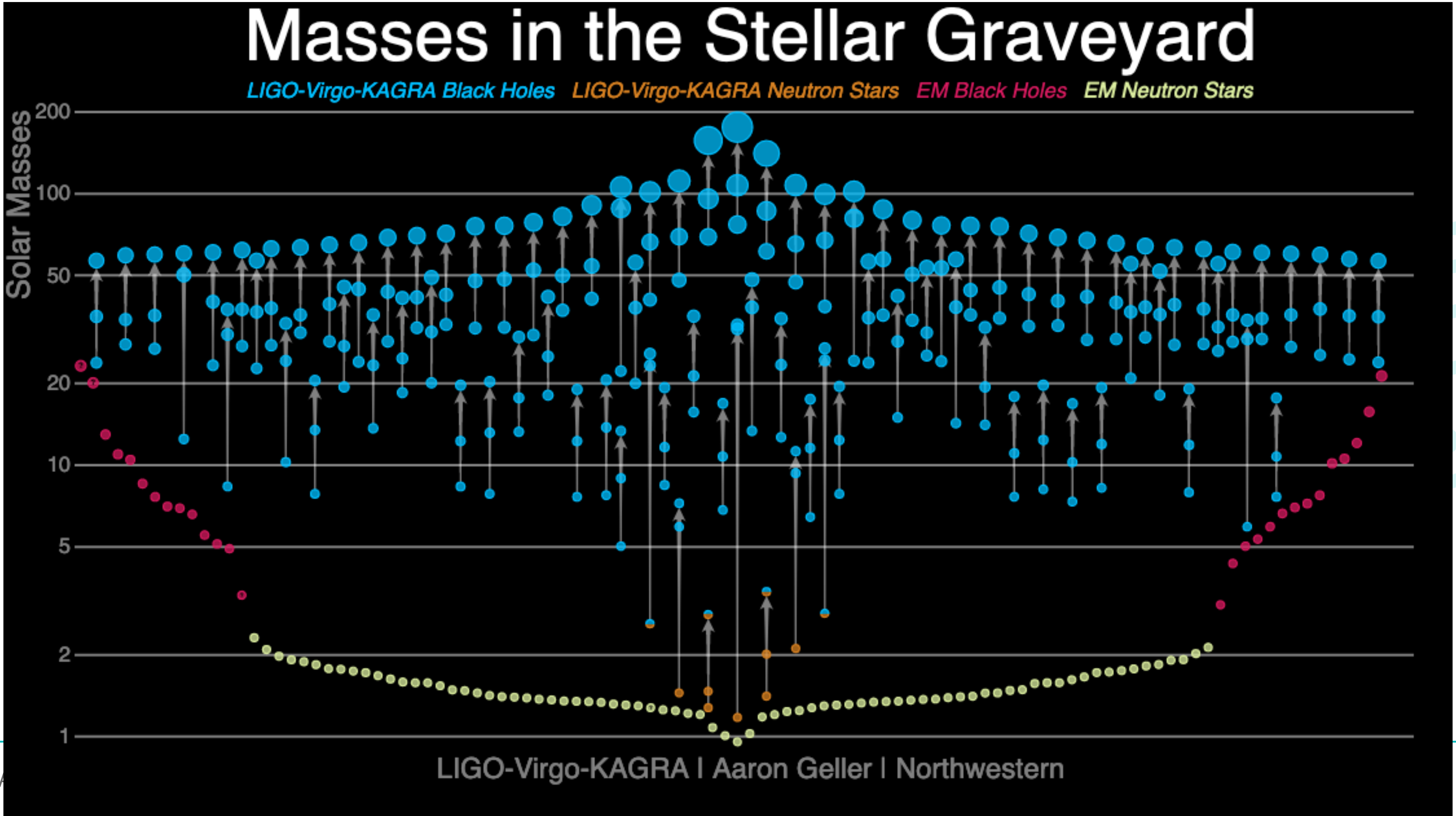
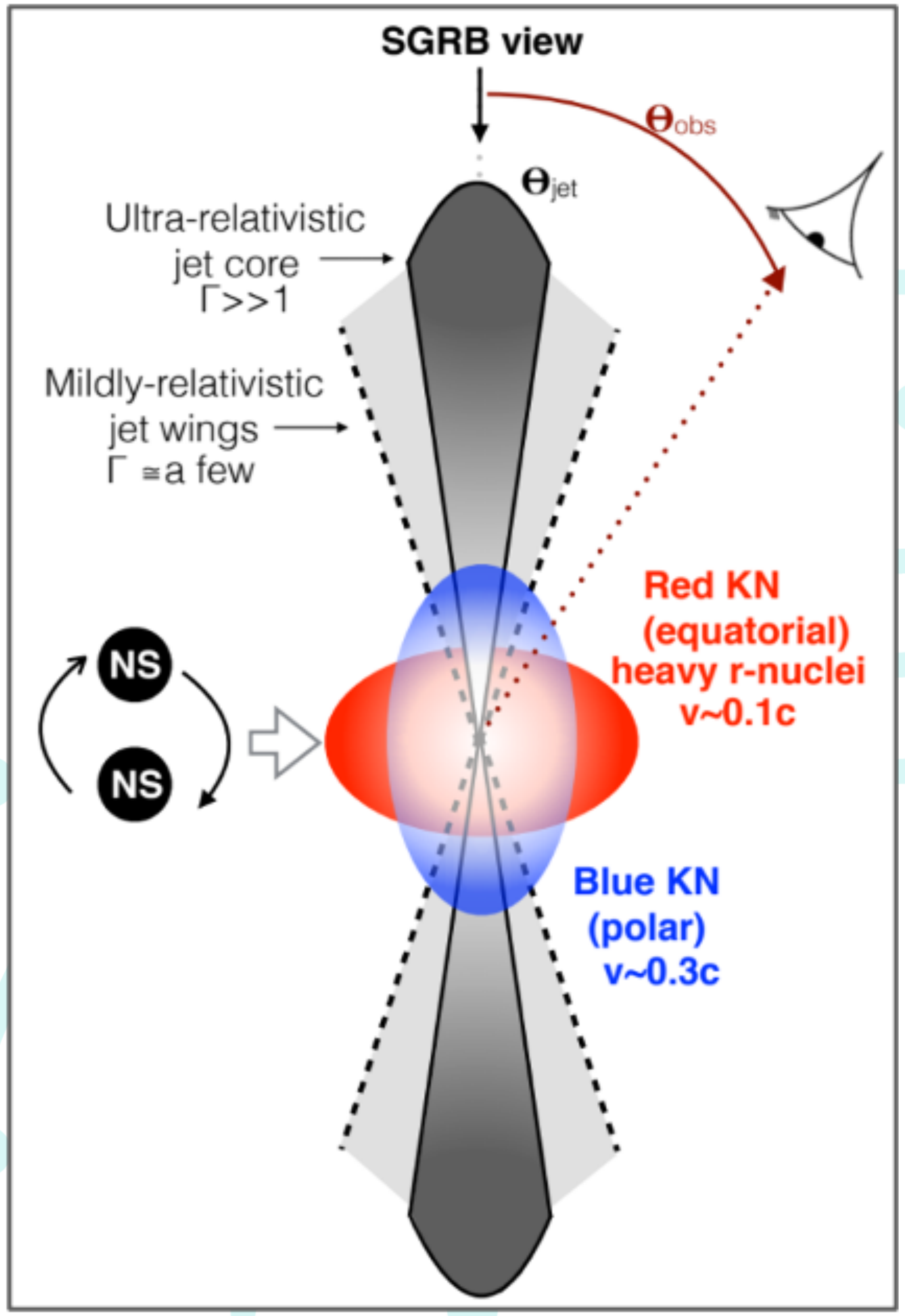
GW detections are discovering new and unexpected populations of compact object binaries.

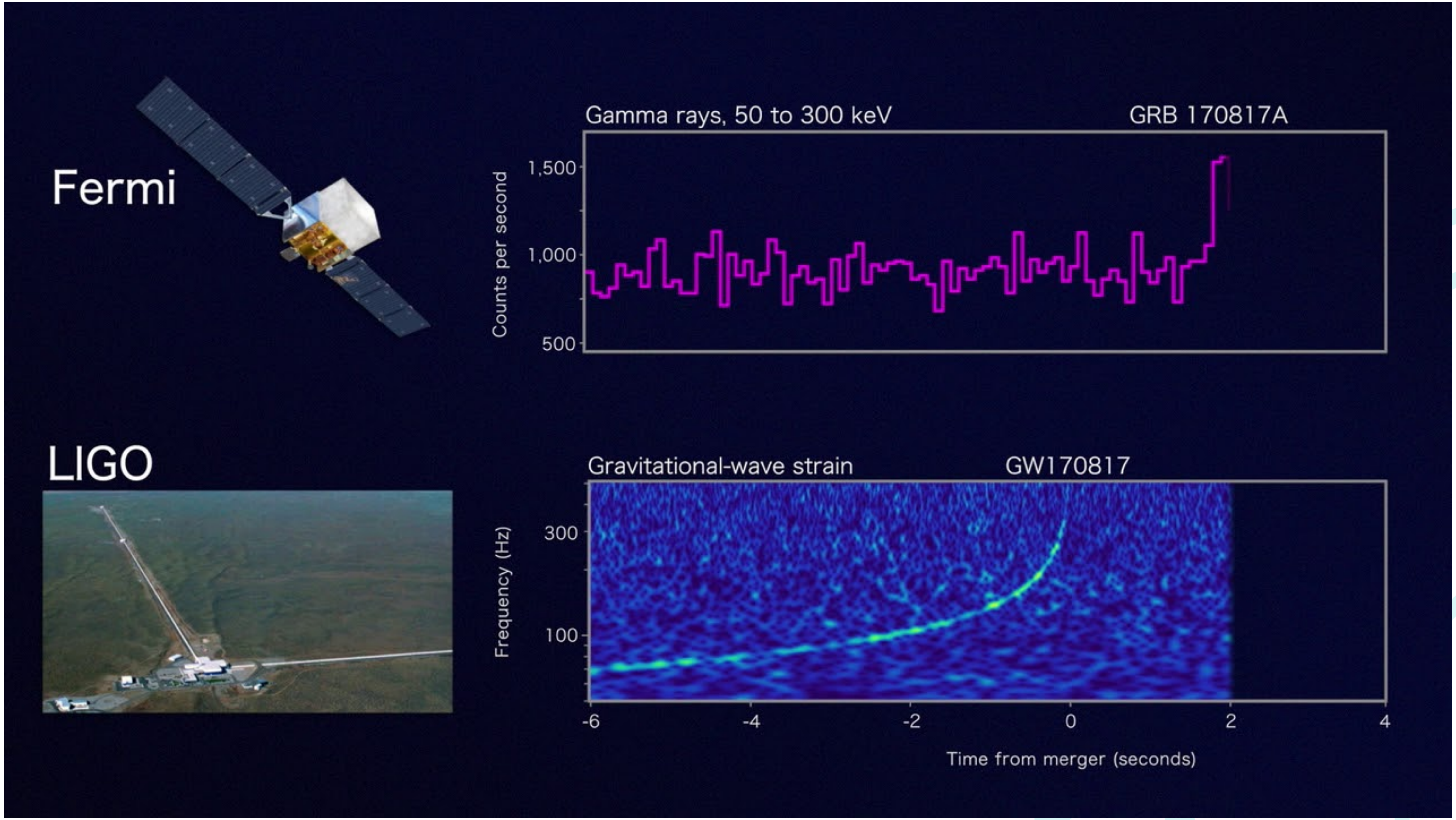


BNS mergers also produce EM radiation.



Margutti & Chornock 21

GW170817 remains the only BNS merger for which we have detected an EM counterpart.



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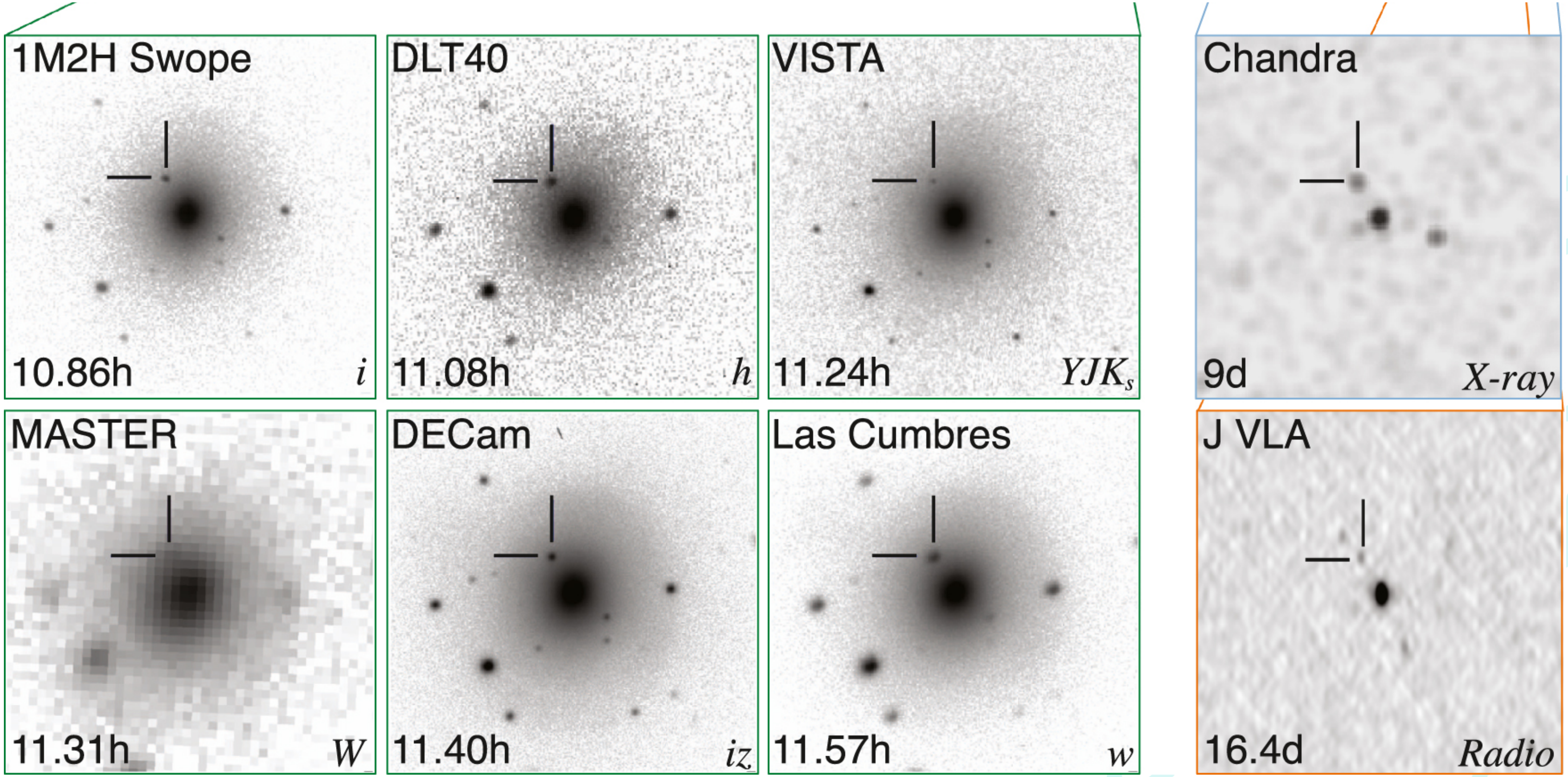
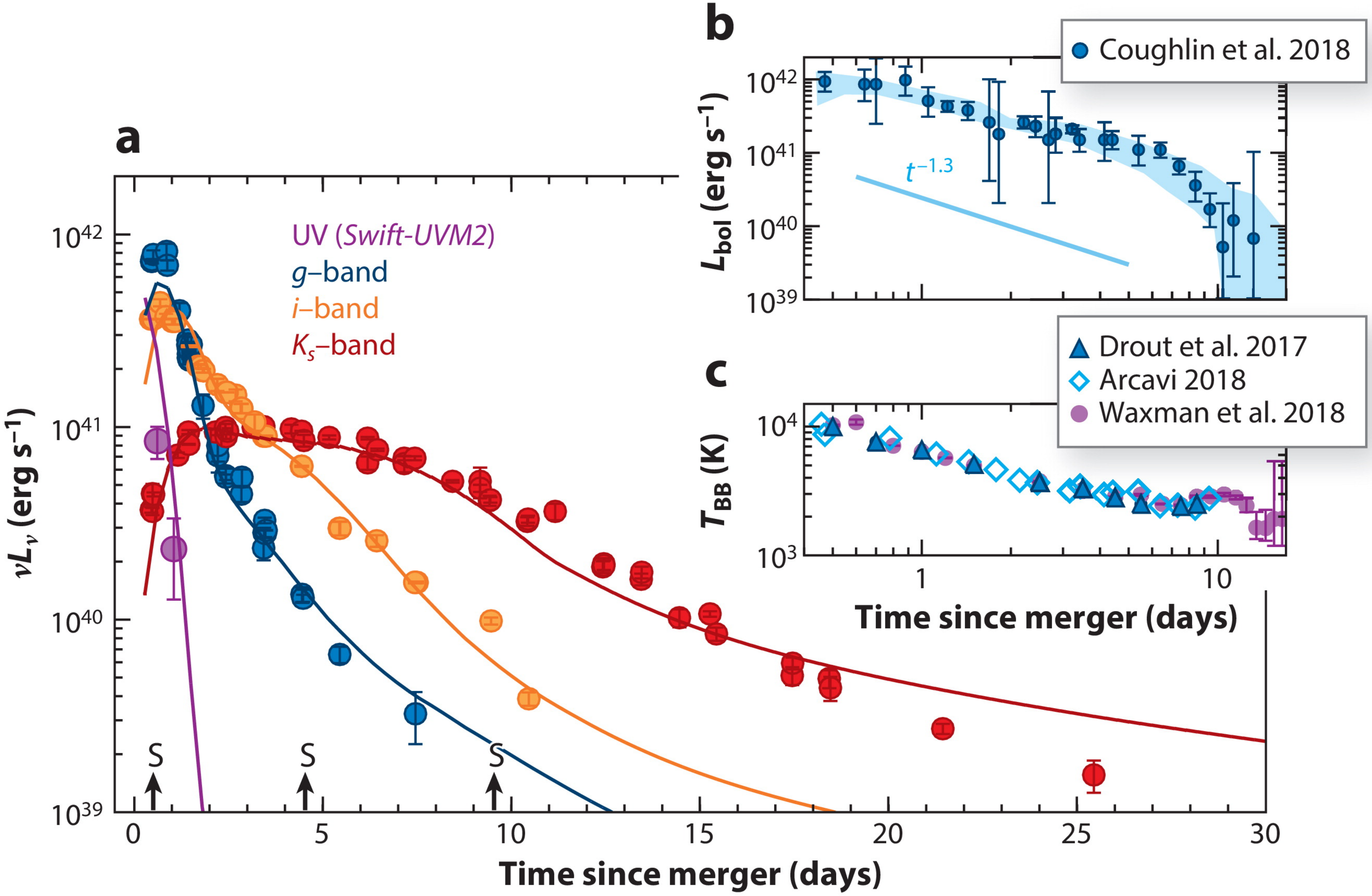


Abbot+17

Detecting EM counterparts can unlock important astrophysics.



implications for:

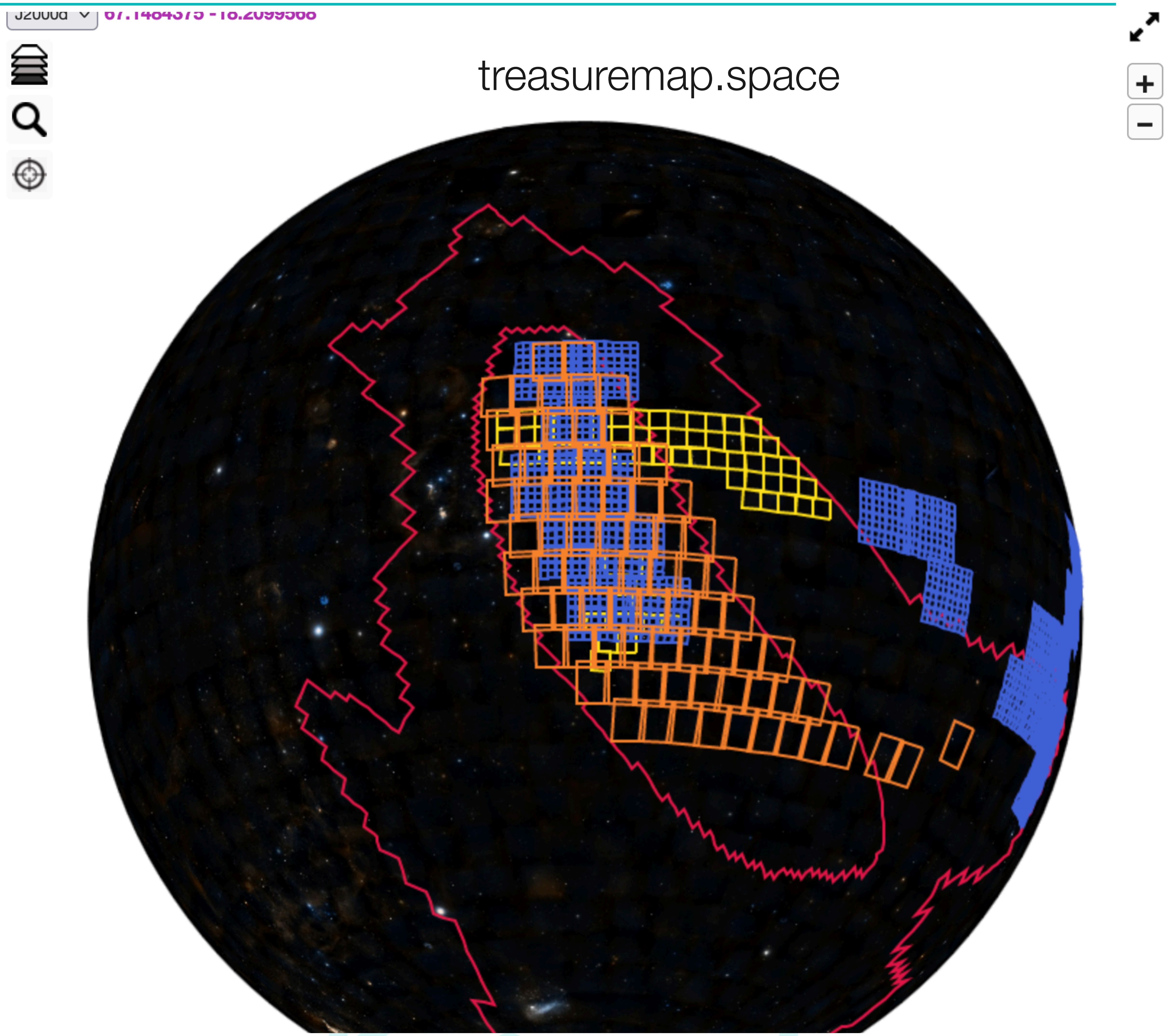
- massive stellar evolution
- relativistic jets & short GRBs
- r-process nucleosynthesis
- cosmology

Margutti R, Chornock R. 2021
Annu. Rev. Astron. Astrophys. 59:155–202

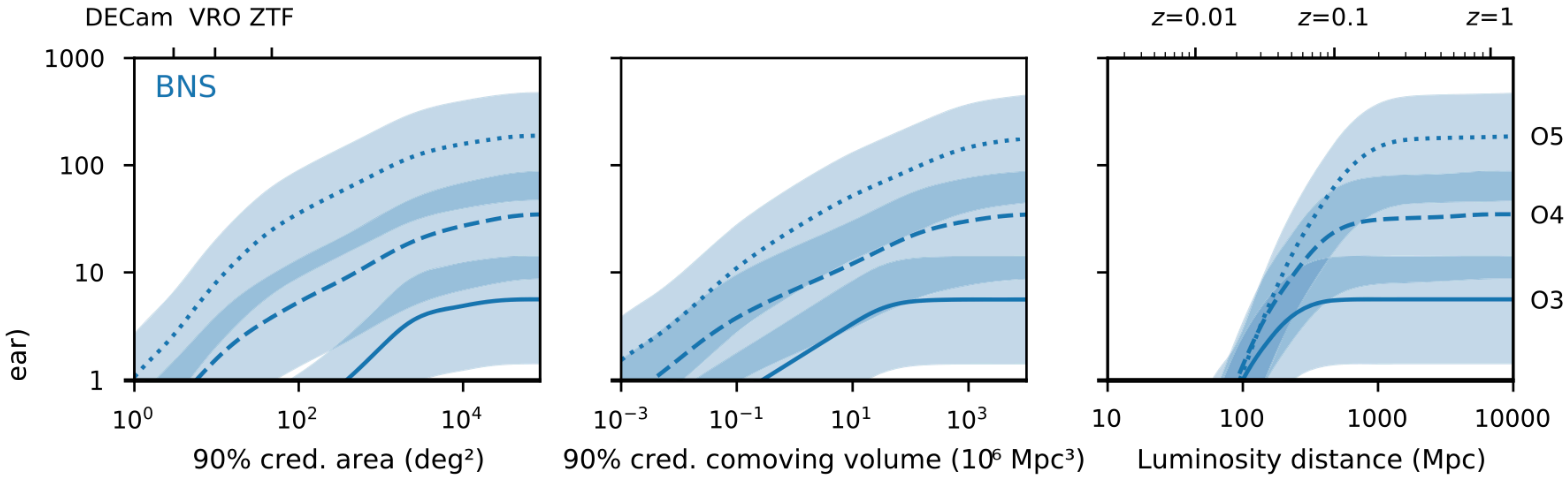
GW interferometers issue alerts and the MMA community performs followup.

JSON | **Avro**

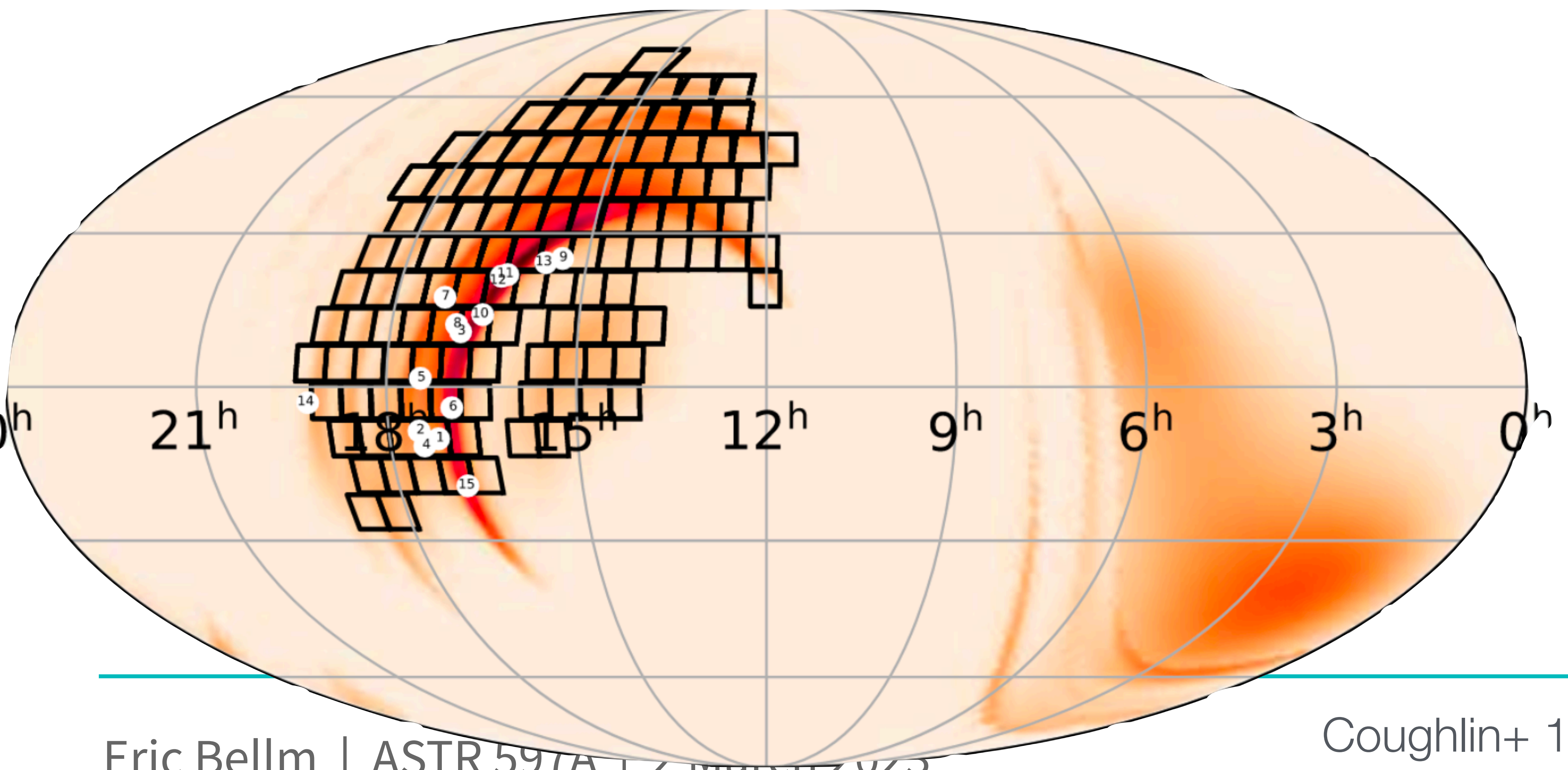
alert_type	`{EarlyWarning,Preliminary,Initial,Update,Retraction}`
time_created	Time notice was created (UTC, ISO-8601) `2018-11-01T22:34:20Z`
superevent_id	GraceDB ID: `[{T,M}]SYYMMDDabc`. Example: `MS181101abc`
event	
time	Time of event (UTC, ISO-8601), e.g. `2018-11-01T22:22:46.654Z`
far	Estimated FAR in Hz
instruments	List of detectors, e.g. `['H1', 'L1','V1']` whose data have been used by the online pipeline that has produced the preferred event for that particular superevent
skymap	The contents of a sky map in a multi-order FITS format as a byte-string.



Discovery of EM counterparts is and will remain challenging.



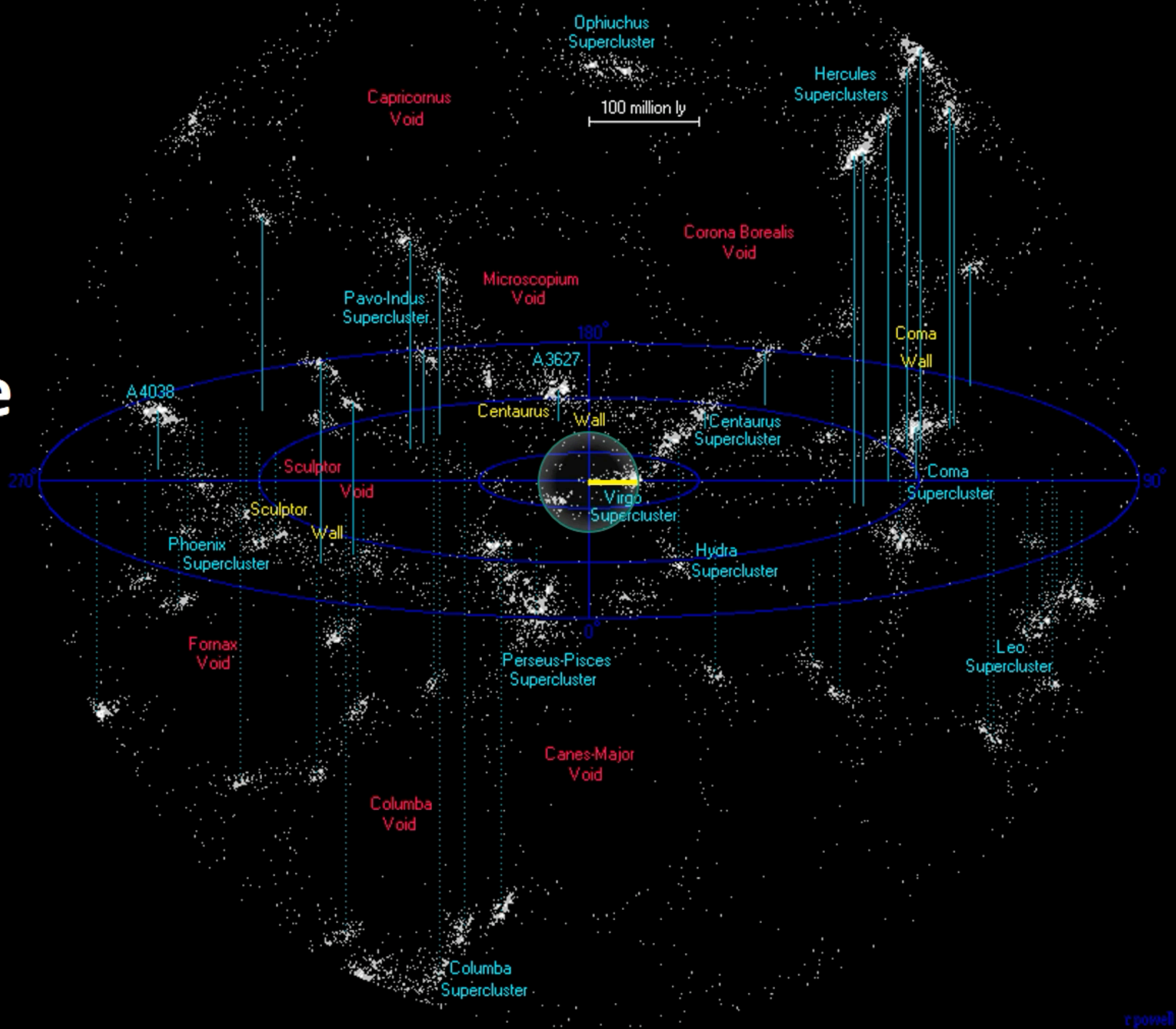
Petrov+22



Coughlin+ 19

Map base: http://www.atlasoftheuniverse.com/index.html
Animation: Caltech/MIT/LIGO Lab/Kim Burtnyk

iLIGO Range Radius: 15 Mpc



Initial LIGO Range: 15 Mpc

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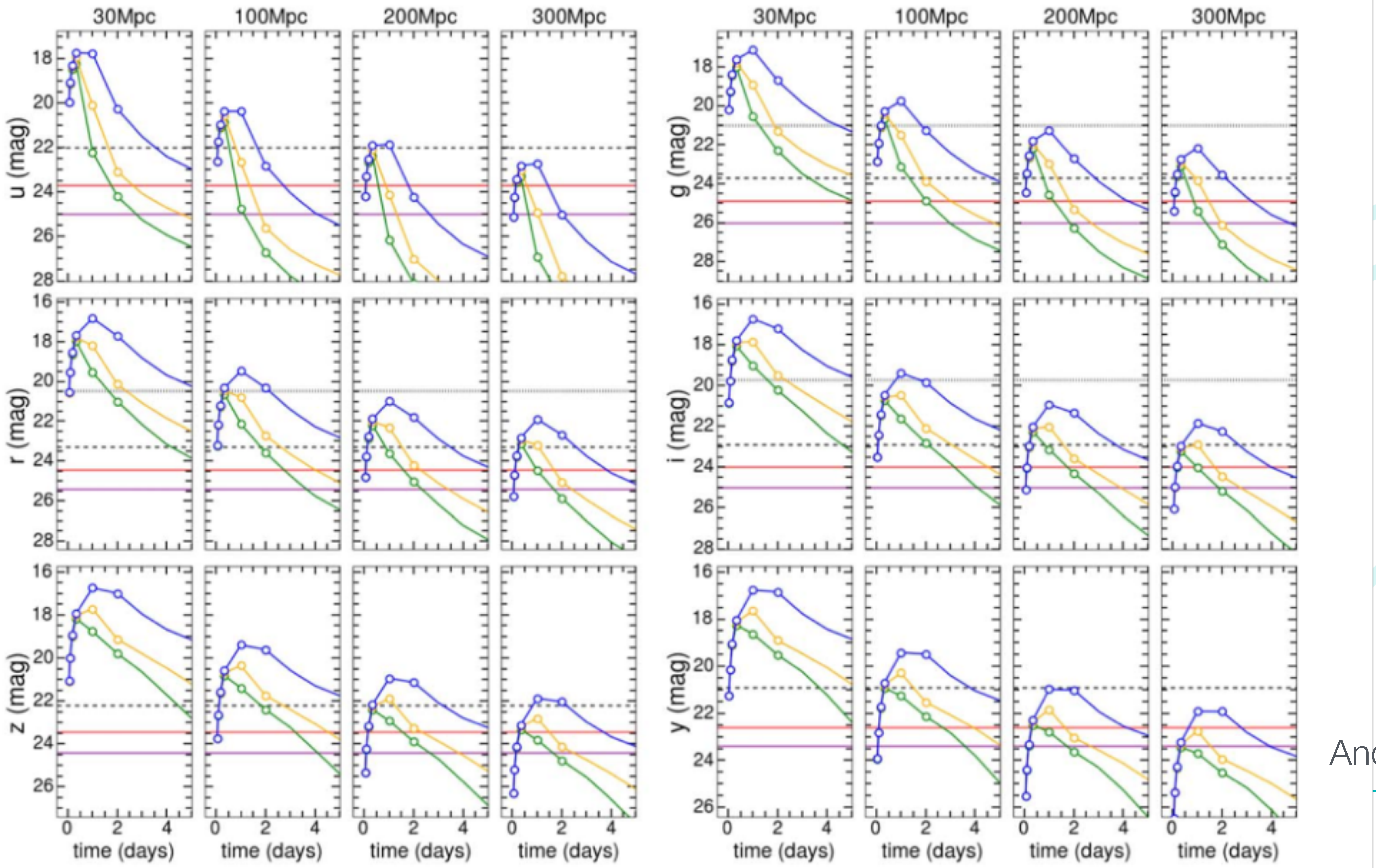
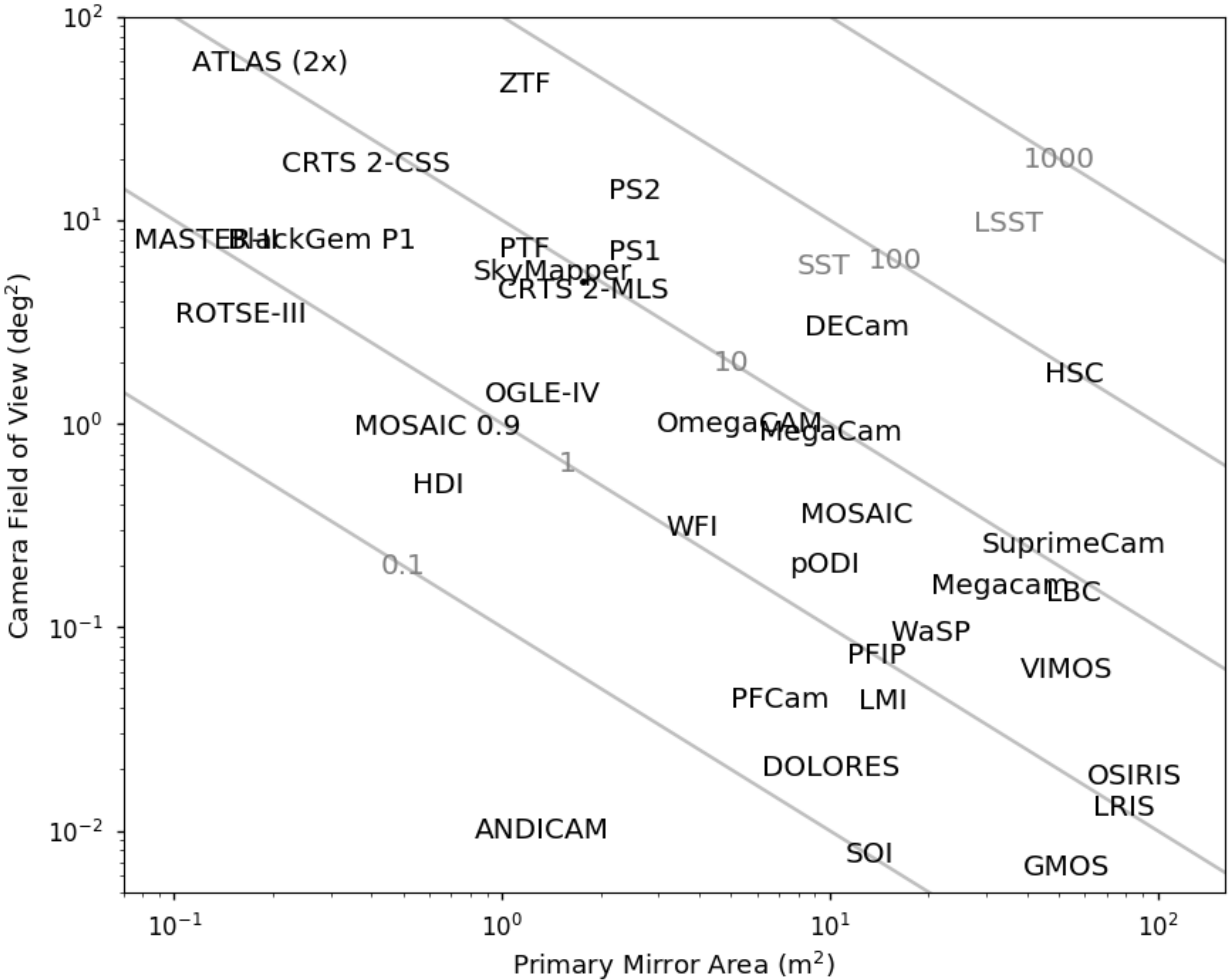
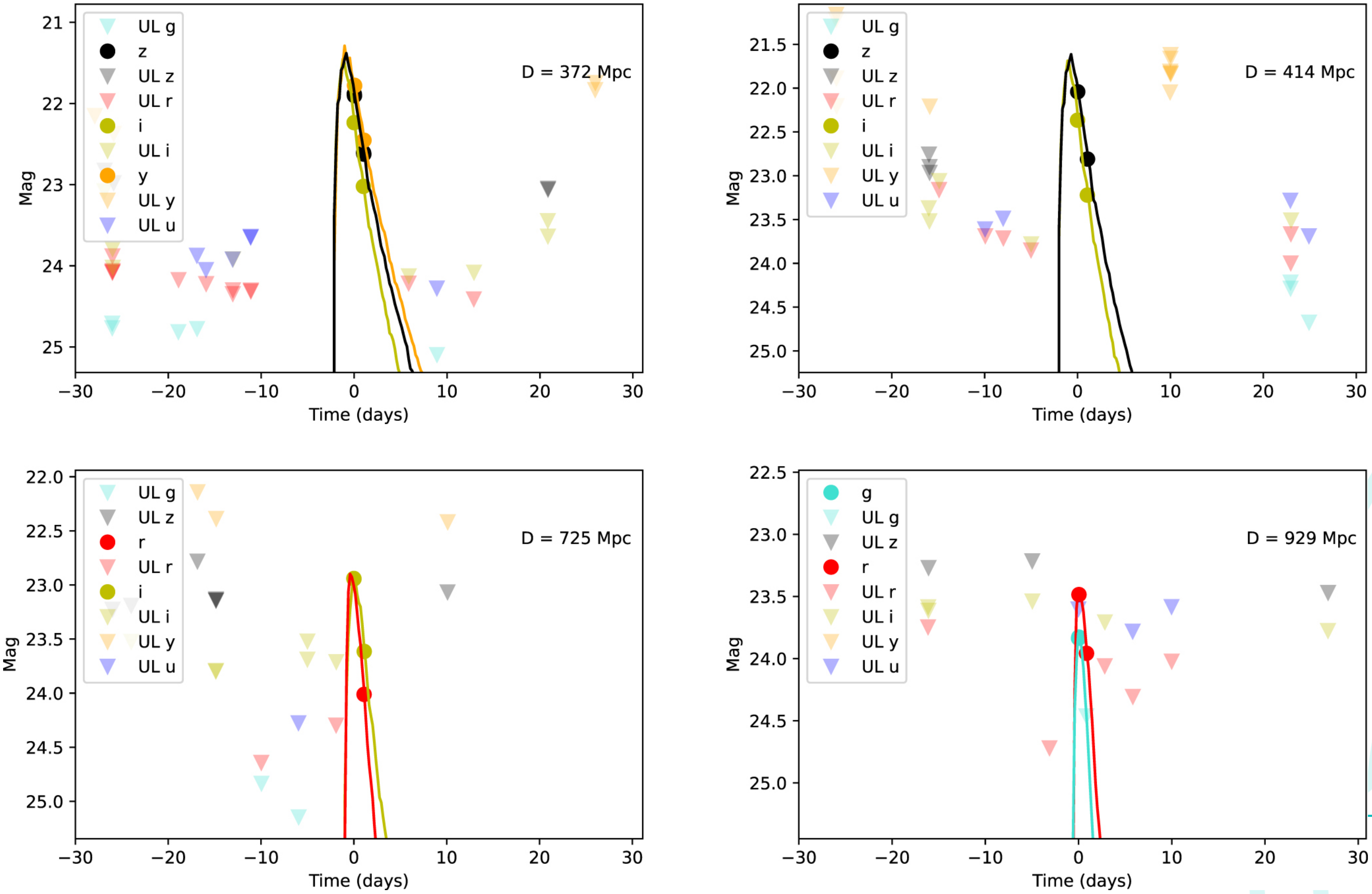


Andreoni+22

Rubin Observatory is the most capable facility for identifying OIR counterparts.



The main LSST survey will not find many kilonovae serendipitously.



only 3-30 KNe would be recognized in realtime in the main Rubin survey.

Andreoni+22

Rubin will devote a few percent of its survey to TOO observations.

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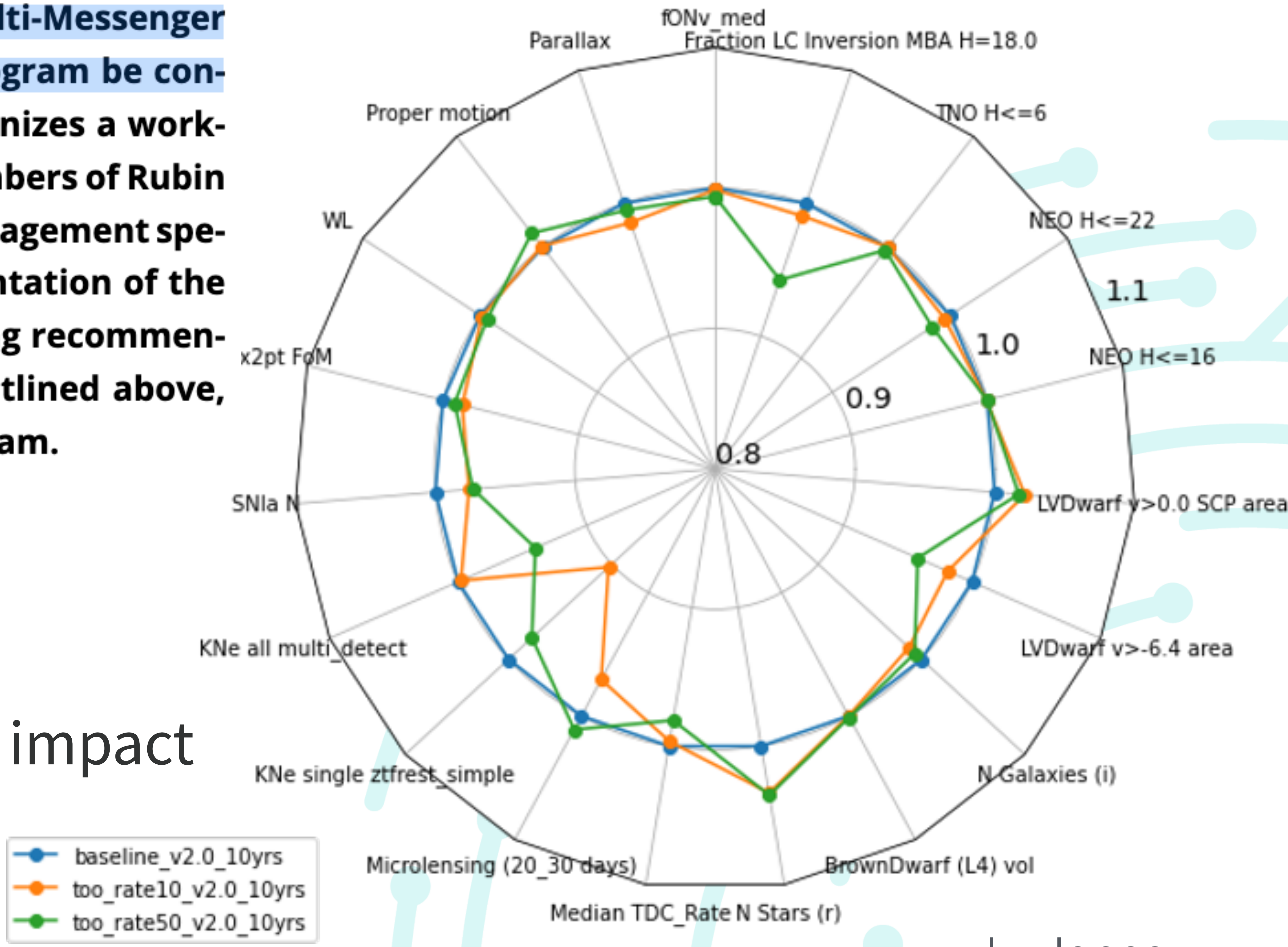
With the existing community studies as guidance, the SCOC recommends that a ToO program to respond to Gravitational Waves and potentially other Multi-Messenger astronomy triggers be established. The SCOC recommends that this program be contained to ≲3% of the LSST time. The SCOC recommends that Rubin organizes a workshop in 2023 to bring together members of the scientific community, members of Rubin Observatory (including observing and scheduler specialists, and Data Management specialists) and members of the SCOC to define the details of the implementation of the Rubin ToO program. This workshop should produce a document detailing recommendations for implementation, including suggestions for the questions outlined above, that the experts agree would accomplish the scientific goals of the program.

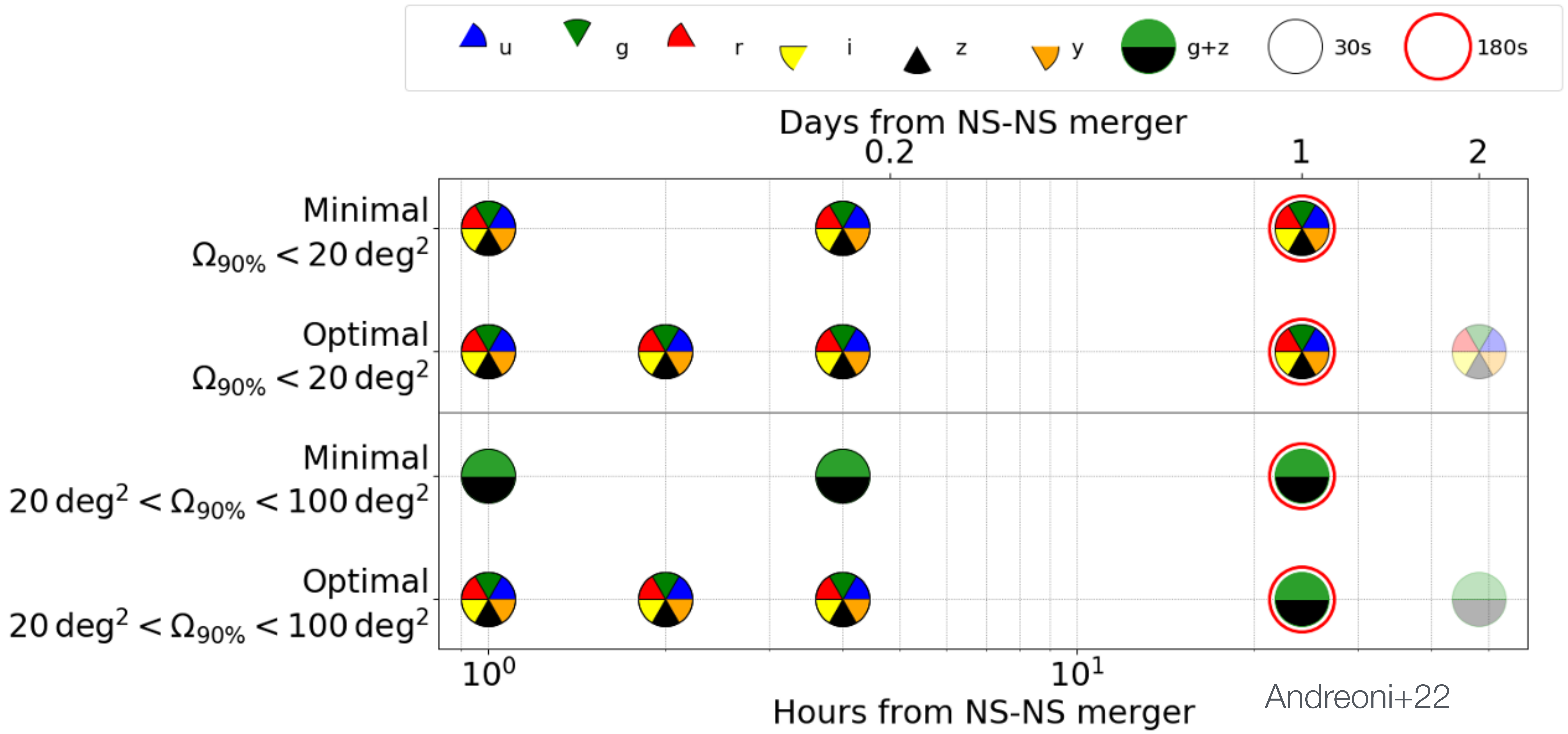
pstn-055.lsst.io



TOOs can have minimal impact on the main survey

L. Jones

Systematic Rubin TOO observations can explore the diversity of compact object merger outcomes.



Andreoni+22

The O4 observing timeline presents challenges for Rubin followup.

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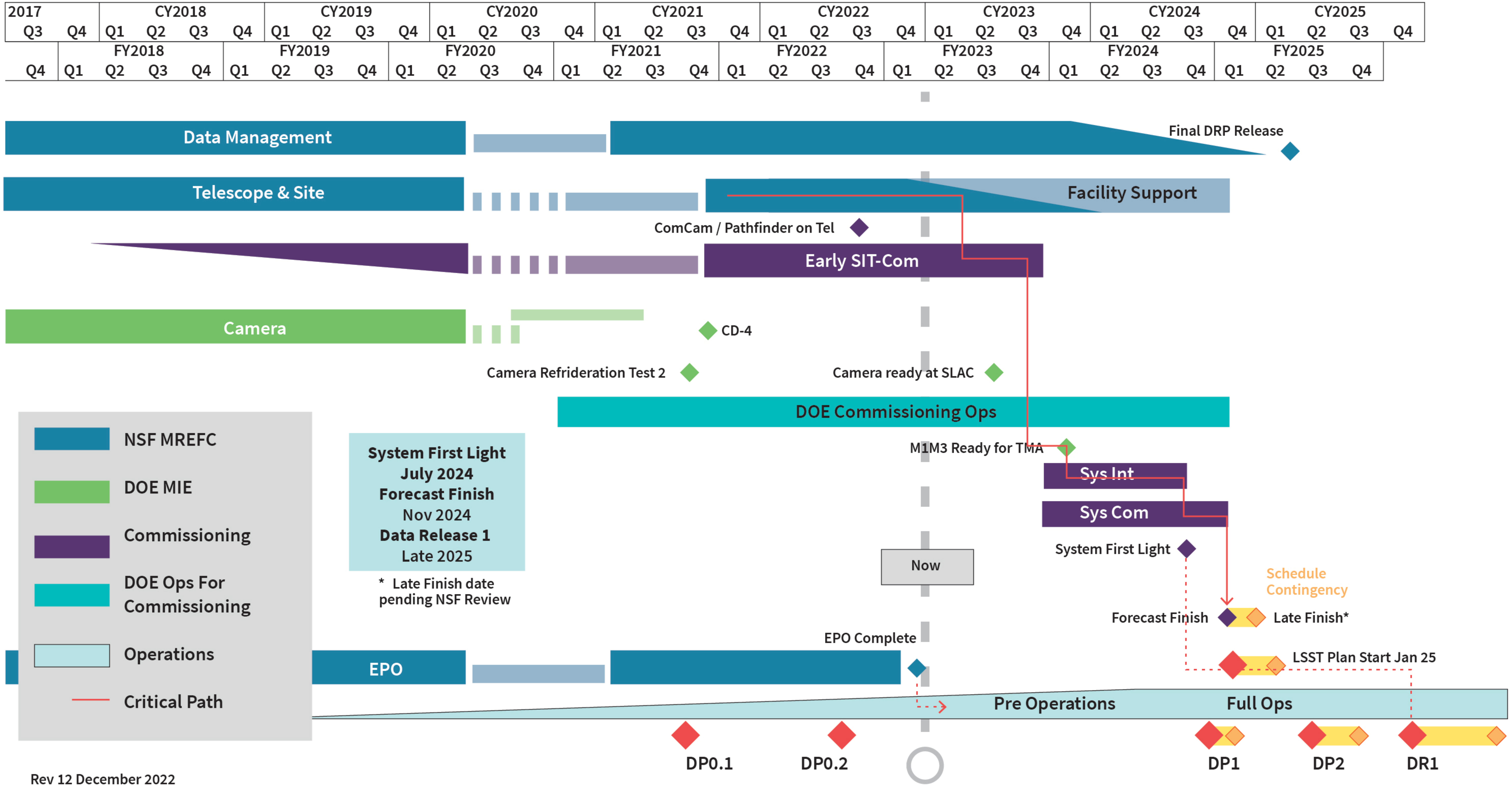


Eric Bel

Rev 12 December 2022

The O4 observing timeline presents challenges for Rubin followup.

During O5 and beyond, regular alert production will support rapid dissemination of TOO counterparts to community brokers.

Rubin has agreed to send the full alert stream to seven brokers; others will operate downstream.

Seven brokers were selected for direct access to the full alert stream:

- ALeRCE
- AMPEL
- ANTARES
- Babamul
- Fink
- Lasair
- Pitt-Google

Two additional brokers were recommended to operate downstream:

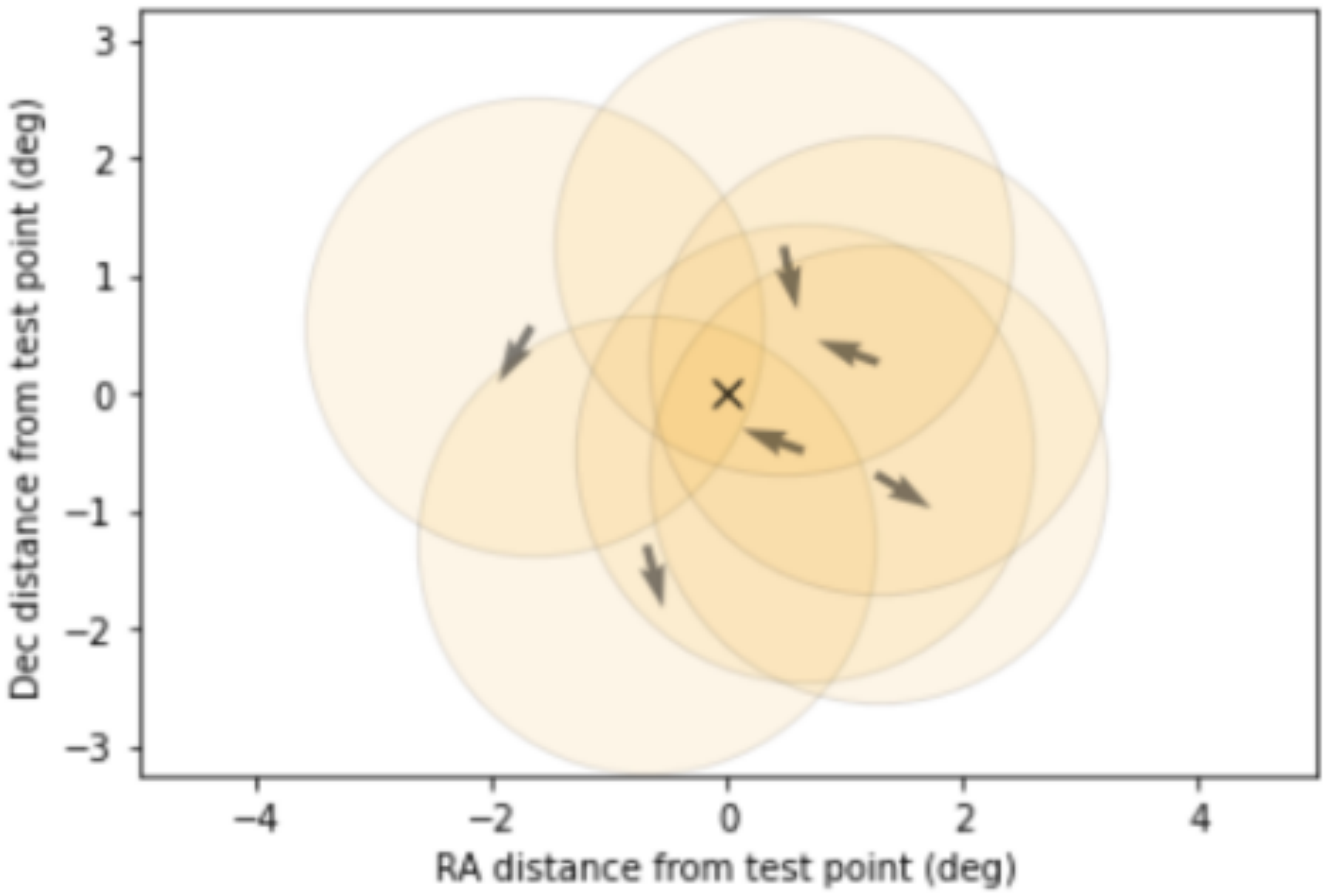
- SNAPS
- POI/Variables

TOO observations in the early survey present data processing challenges.

LSST's images are heavily dithered and rotated ⇒ spatially contiguous coadded "template" images are needed for difference imaging.

During commissioning and early operations there will not yet be enough images available to make templates covering the whole sky in all filters.

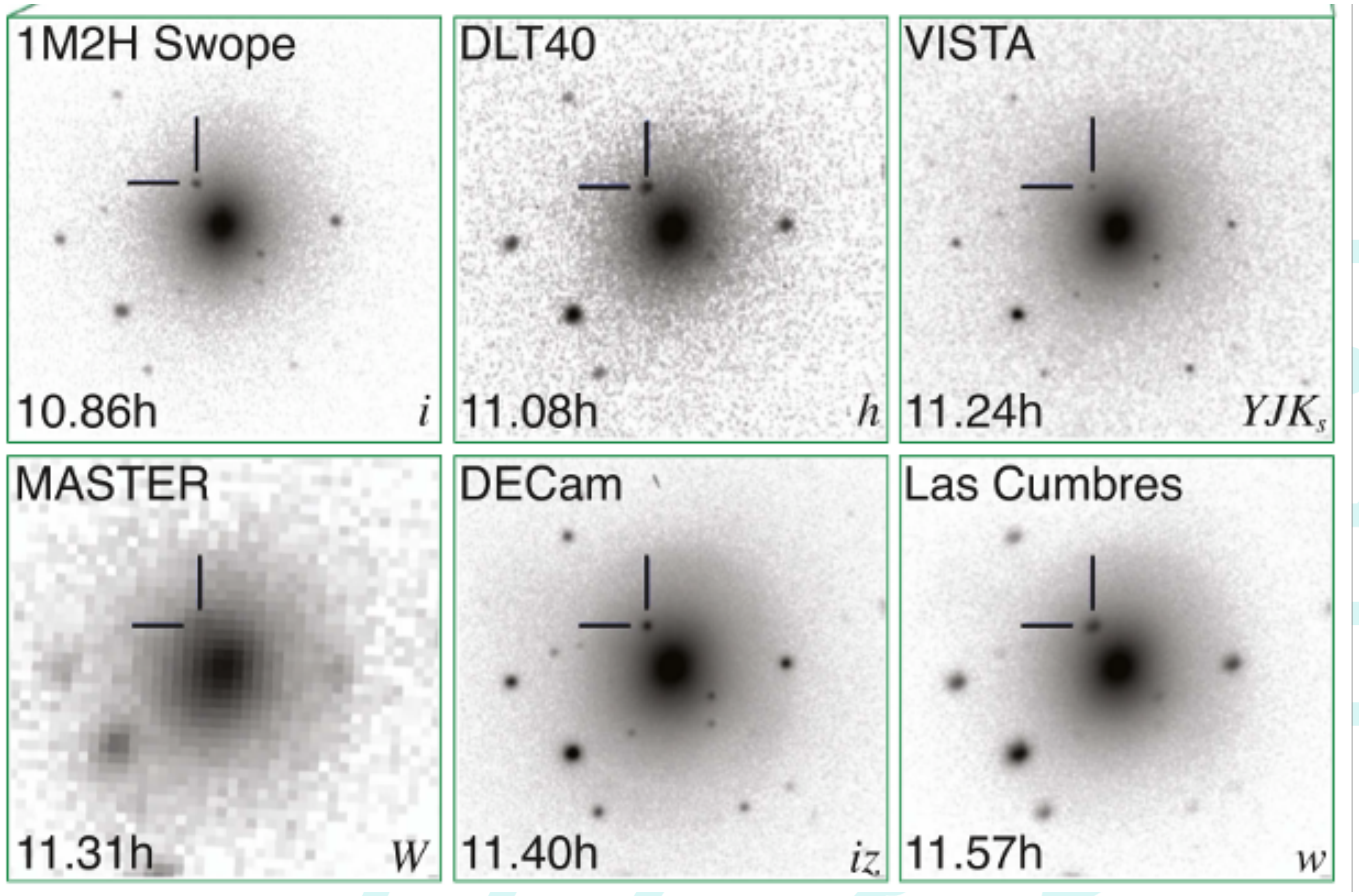
It is thus probable that automated alerts will not be possible for any O4 TOO observations.



TOO observations prior to DR1 may require manual data processing by the Rubin team.

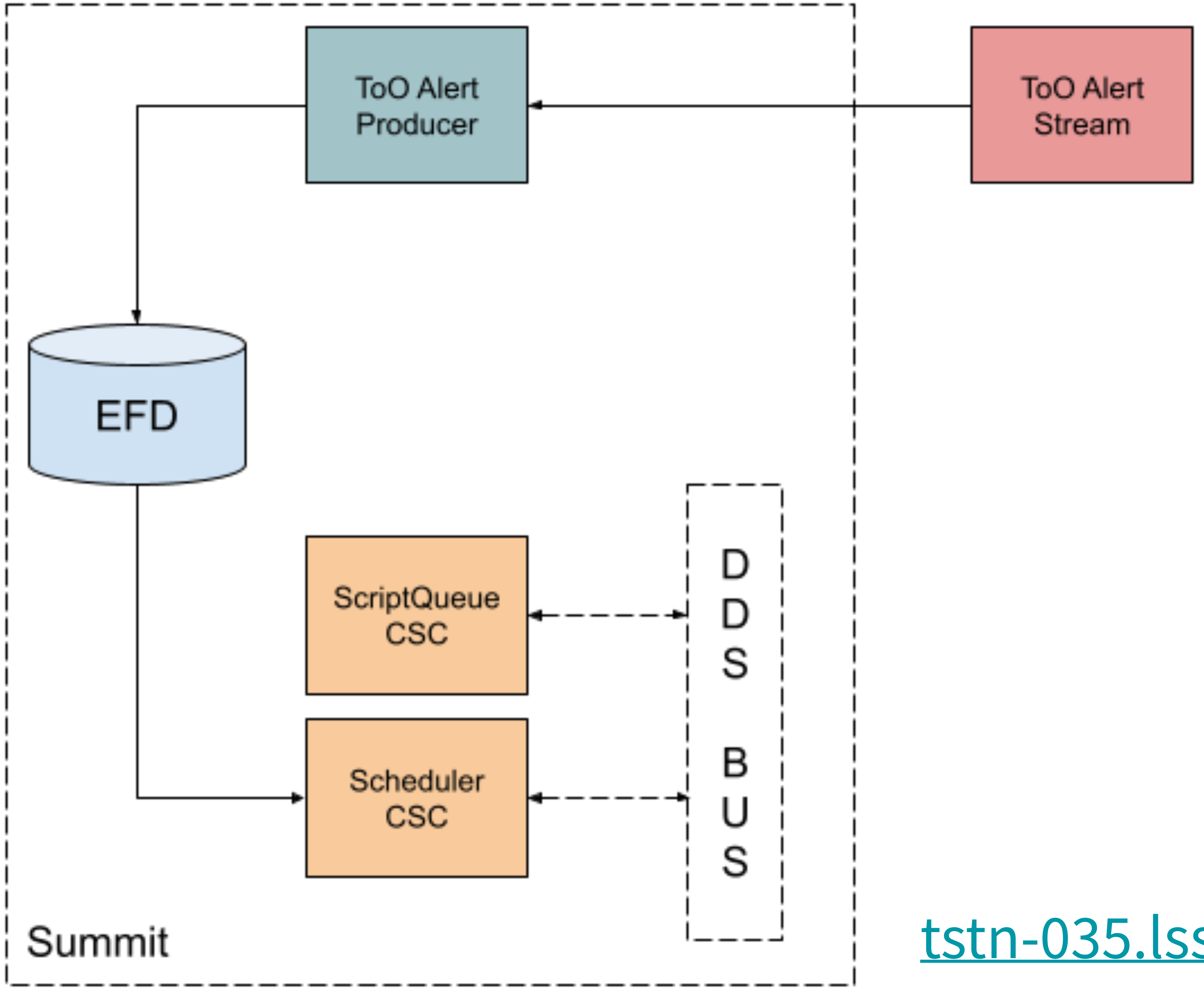
Even without automated Alert Production, best-effort manual processing by Rubin staff can still enable timely reporting of candidate TOO counterparts (e.g., via GCN):

- Identification of extreme color or temporally evolving direct-imaging sources
- Image differencing against ad-hoc templates



Resulting need for "on-call" staff imply selection and prioritization of TOO observations will be needed in this period.

TOO observing modes will be tested during commissioning.



tstn-035.lsst.io

Other sources of TOO observations can be contemplated.

Need time-sensitive followup with uncertain area (> 10 deg^2) and faint counterparts

Relatively few obviously compelling candidates--likely to be a proposal process in the future.

UW graduate students have the opportunity to participate directly in LSST commissioning activities (and science!).

SITCOMTN-050: Summary of In-Kind Contributions to Rubin Observatory System Integration, Test, and Commissioning Efforts

University of Washington: *SIT-Com support*

Point of Contact: Andy Connolly

Members: Andrew Connolly, John Franklin Crenshaw, Dino Bektesevic, Colin Chandler, Sam Wyatt, Pedro Bernardinelli, Yuankun (David) Wang, Steven Stetzler, Jake Kurlander, Chester Li, Max West, Drew Oldag, Carl Christoffersen, Doug Branton, Karlo Mrakovcic

sitcomtn-050.lsst.io

Rubin Observatory will provide a uniquely powerful resource for optical followup and correlative observations of MMA sources.

MMA is just one of several areas where UW grad students can make transformative scientific discoveries!

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