Image credit: DESY

Landscape of electro-magnetic transients

KM3NeT Uitje

Nov 18, 2025

Sjoert van Velzen, Leiden Observatory

Introduction

- Why transients?
  - Less background for neutrino source searches
  - In general:
    - New phase space for discoveries (ie, most of my career)
    - Extreme sources, extreme physics

In this talk

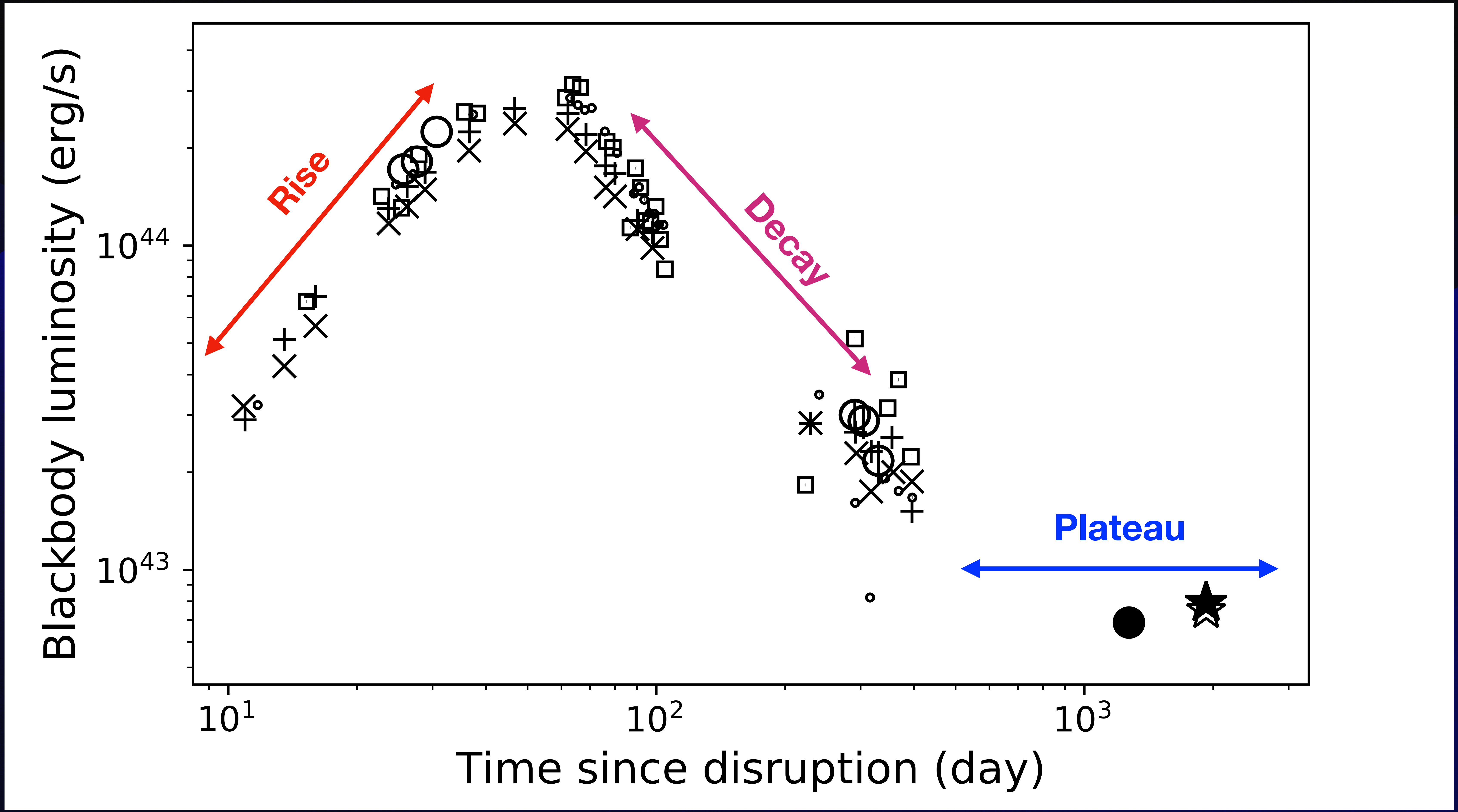
- Example of typical steps in optical transient surveys
- Example of unexpected discovories
- Looking towards the future: Rubin and other facilities

Let’s pick one example EM transient: Tidal disruption events (TDEs)

Artis impression Image credit: NASA, van Velzen et al.
Simulation image: Guillochon et al.

Example light curve

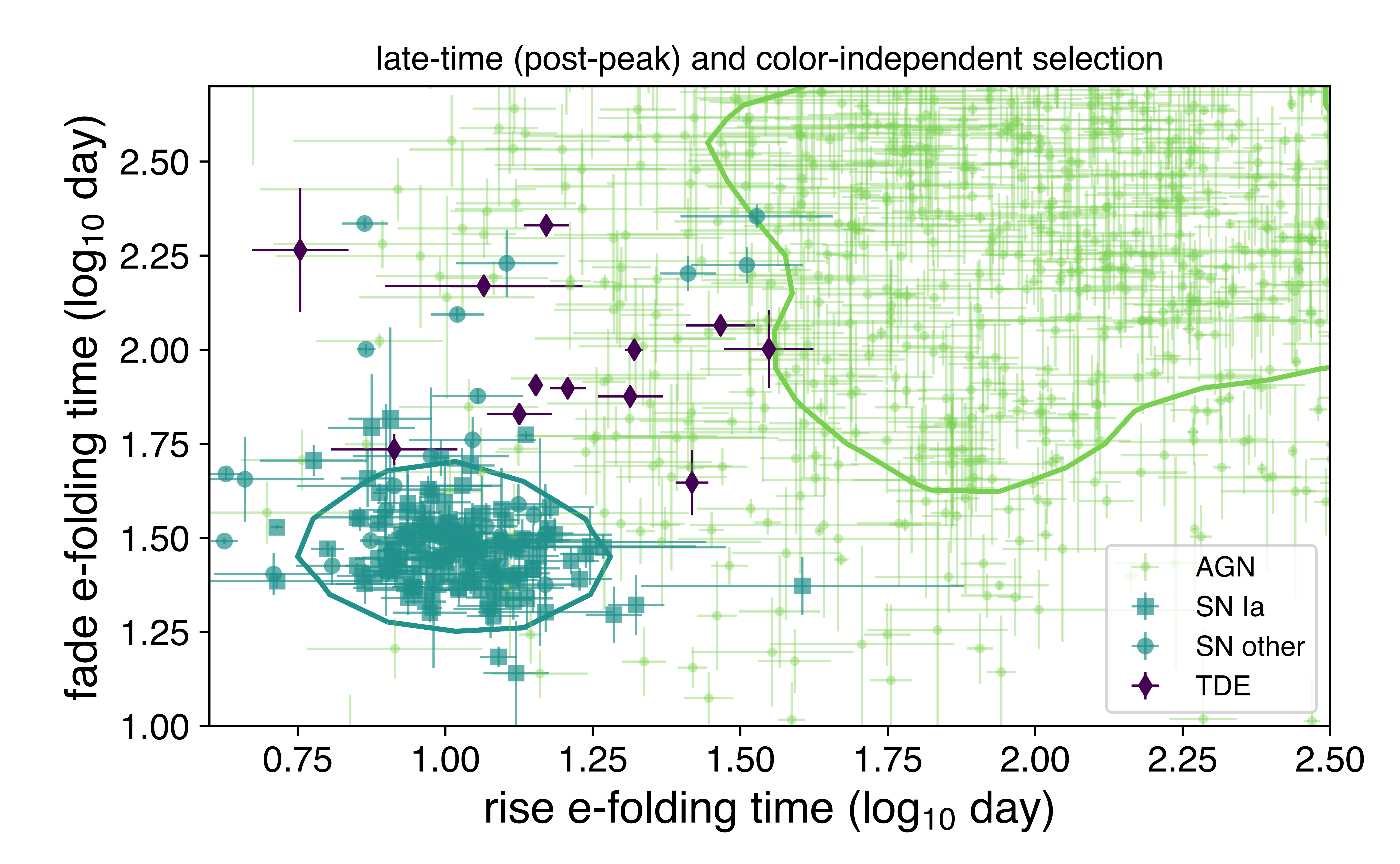
Optical and UV data (5 different observatories)



Data of PS-10jh Gezari et al. (2012, 2015); van Velzen et al. (2019)

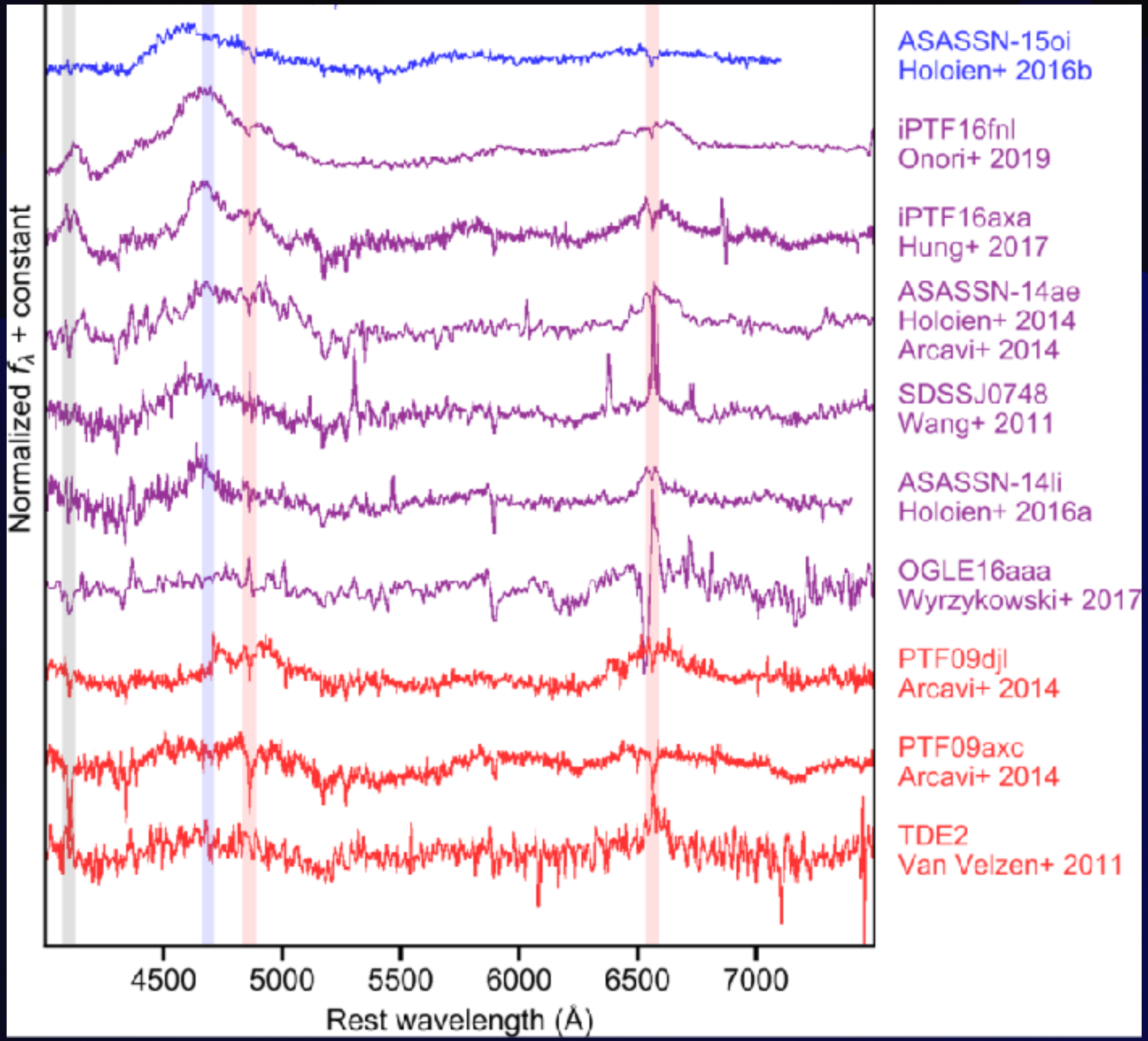
Step 1: find a photometric transients

Image large area of sky very few nights



Step 2: classify using spectrum

Expensive step, requires larger telescope



Step 3: if possible, obtain multi-wavelength coverage

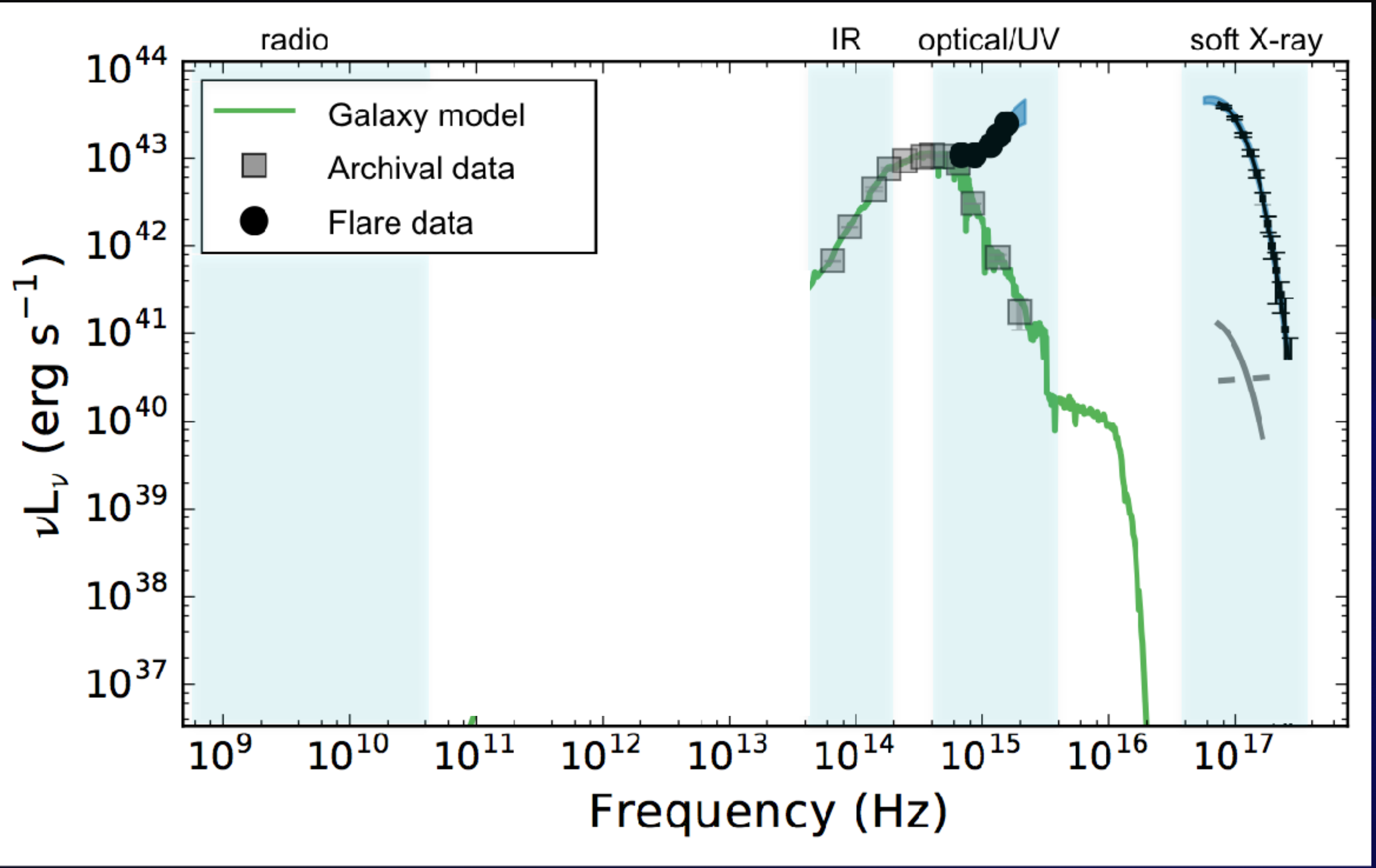


Figure: van Velzen et al. (Science, 2016); showing ASASSN-14li (Holoien et al. 2016)

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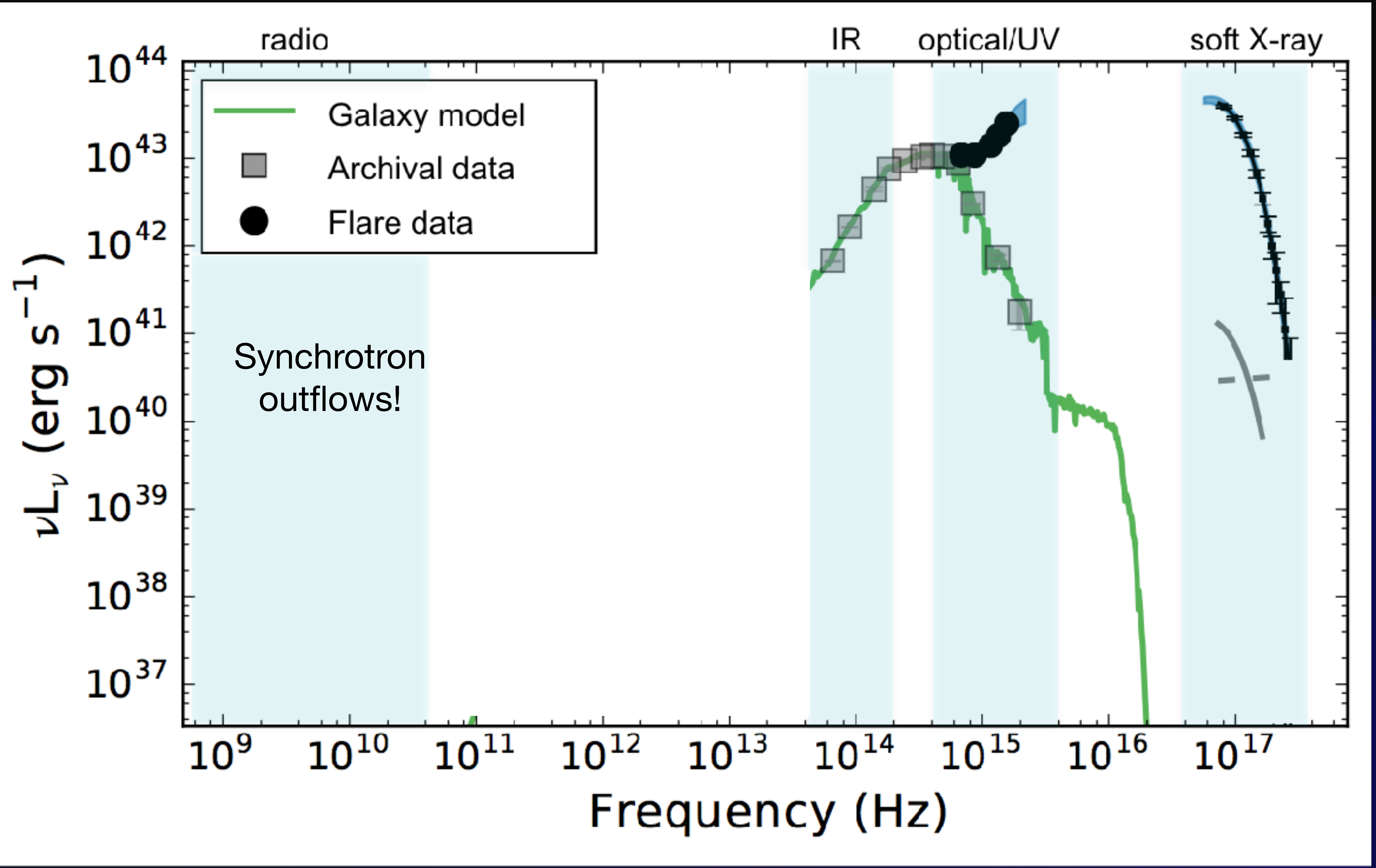

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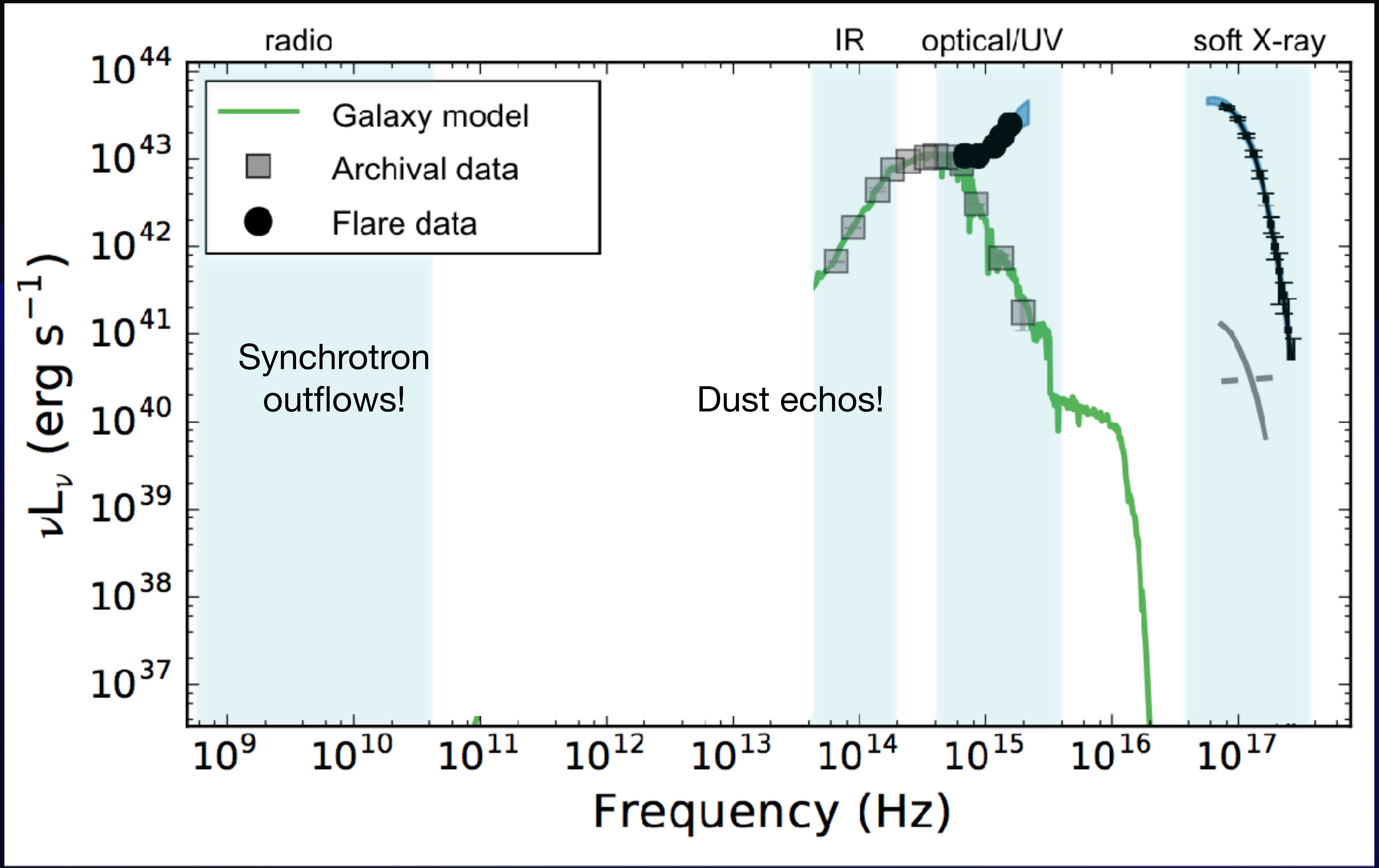

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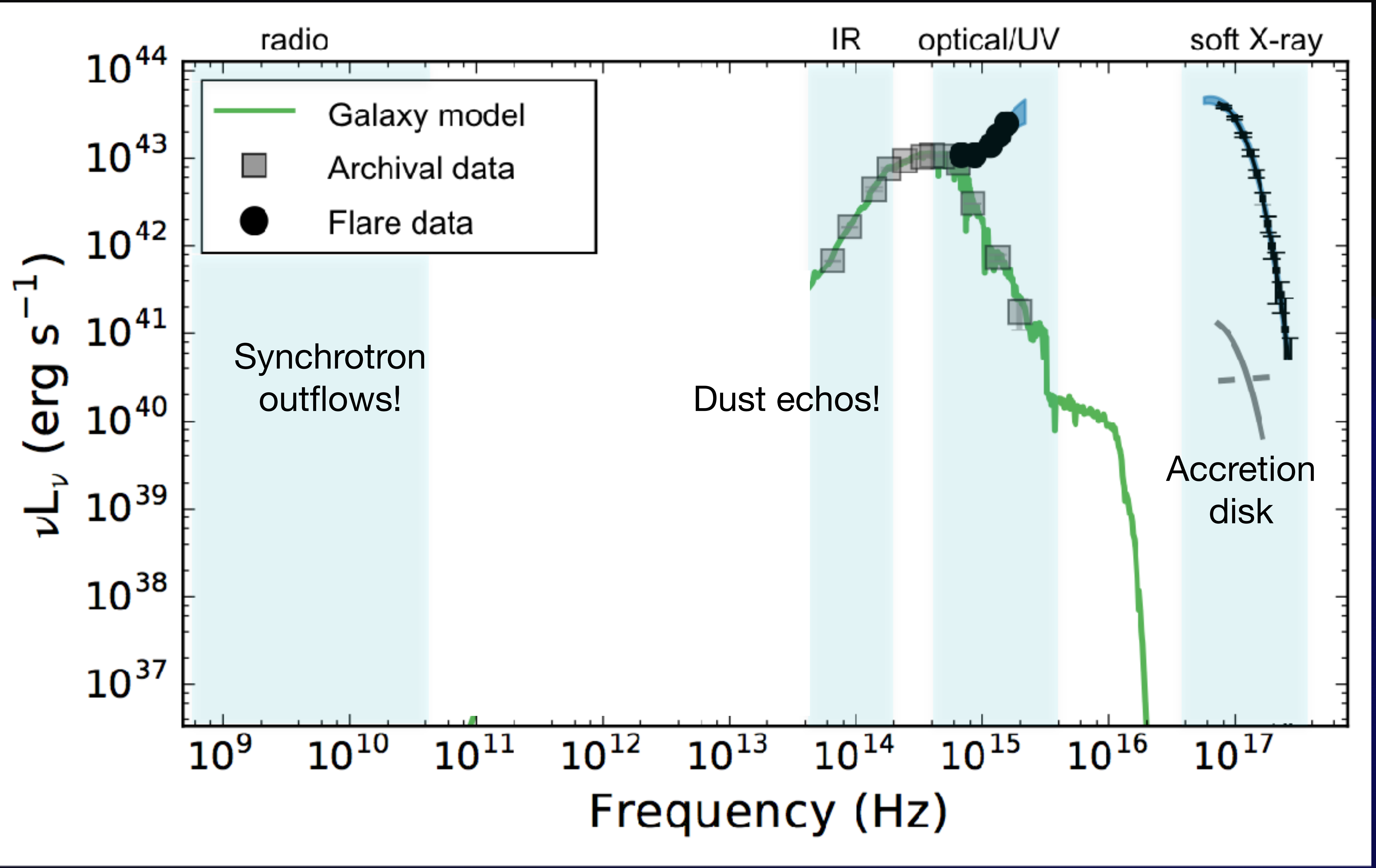

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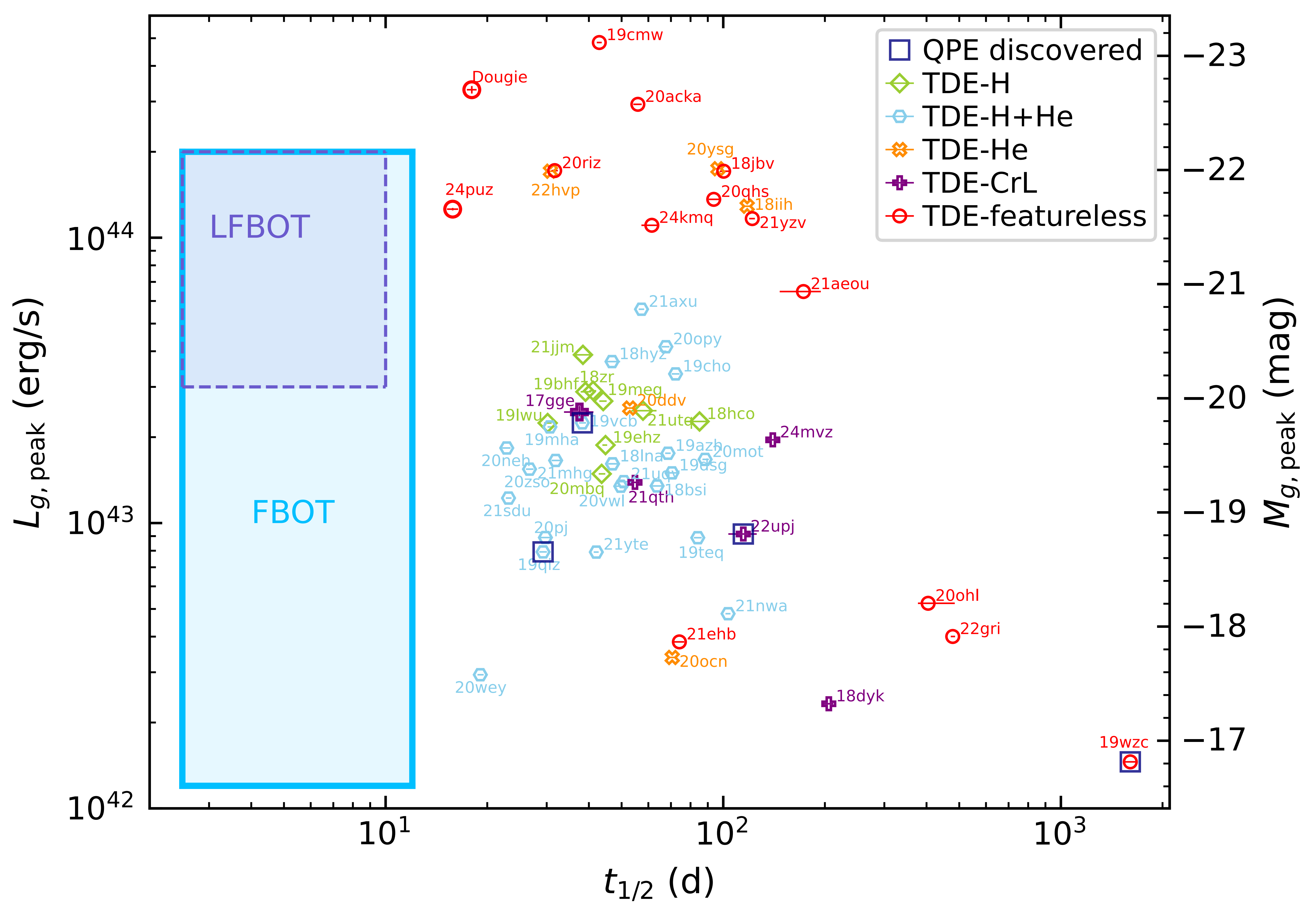
Let's not wander too far into the zoo of (optical) transients



Yao et al. in prep

Example: history of transient jets from supermassive black holes

YEAR	OBSERVATION	*WAVELENGTHS*
2011	Birth of relativistic jet, seen in real-time	*γ-ray; radio follow-up*
2016	Transient sub-relativistic outflows	*optical; radio follow-up*
2021	Late time radio flares	*optical; radio follow-up*
2022	Optically-selected new-born relativistic jets	*optical; γ-ray + radio follow-up*

Never a dull moment

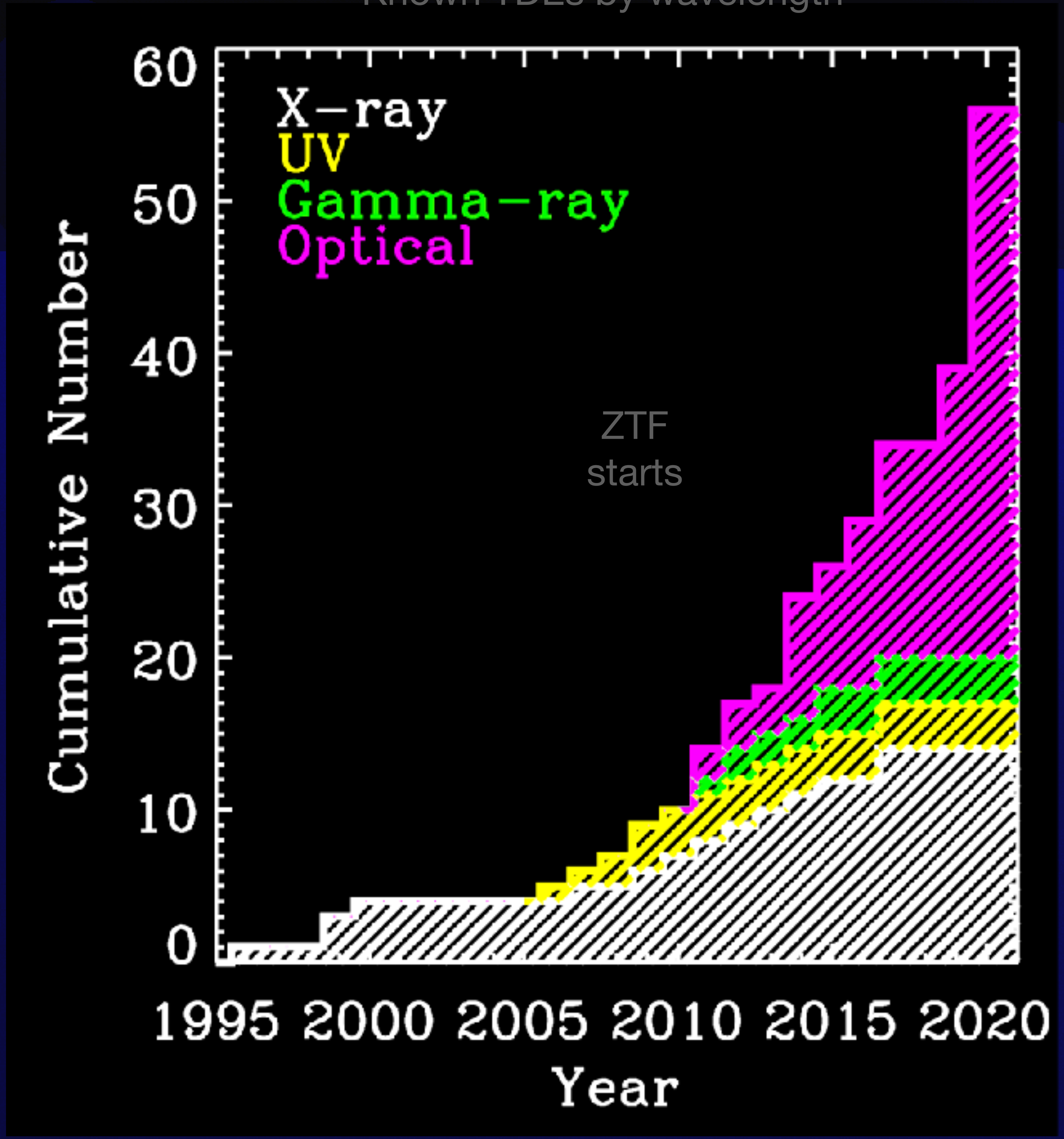
YEAR	OBSERVATION	EXPECTED
2011	Jetted TDE	NO
2021	Late time radio flares	NO*
2022	Optically-selected jetted TDE	NO

Small revolution back in 2019

Zwicky Transient Facility

- Increase in detection rate from ~few per year to ~10 per year
- Bright enough for follow-up
- Very labor intensive
- This doesn't scale to larger rates

Known TDEs by wavelength




HSC,
1.7 deg²
DES,
2.5 deg²
PTF/iPTF, 7.3 deg²
ZTF, 47 deg²
PS1, 7 deg²
LSST, 9.6 deg²
1 deg

Revolution in transient astronomy

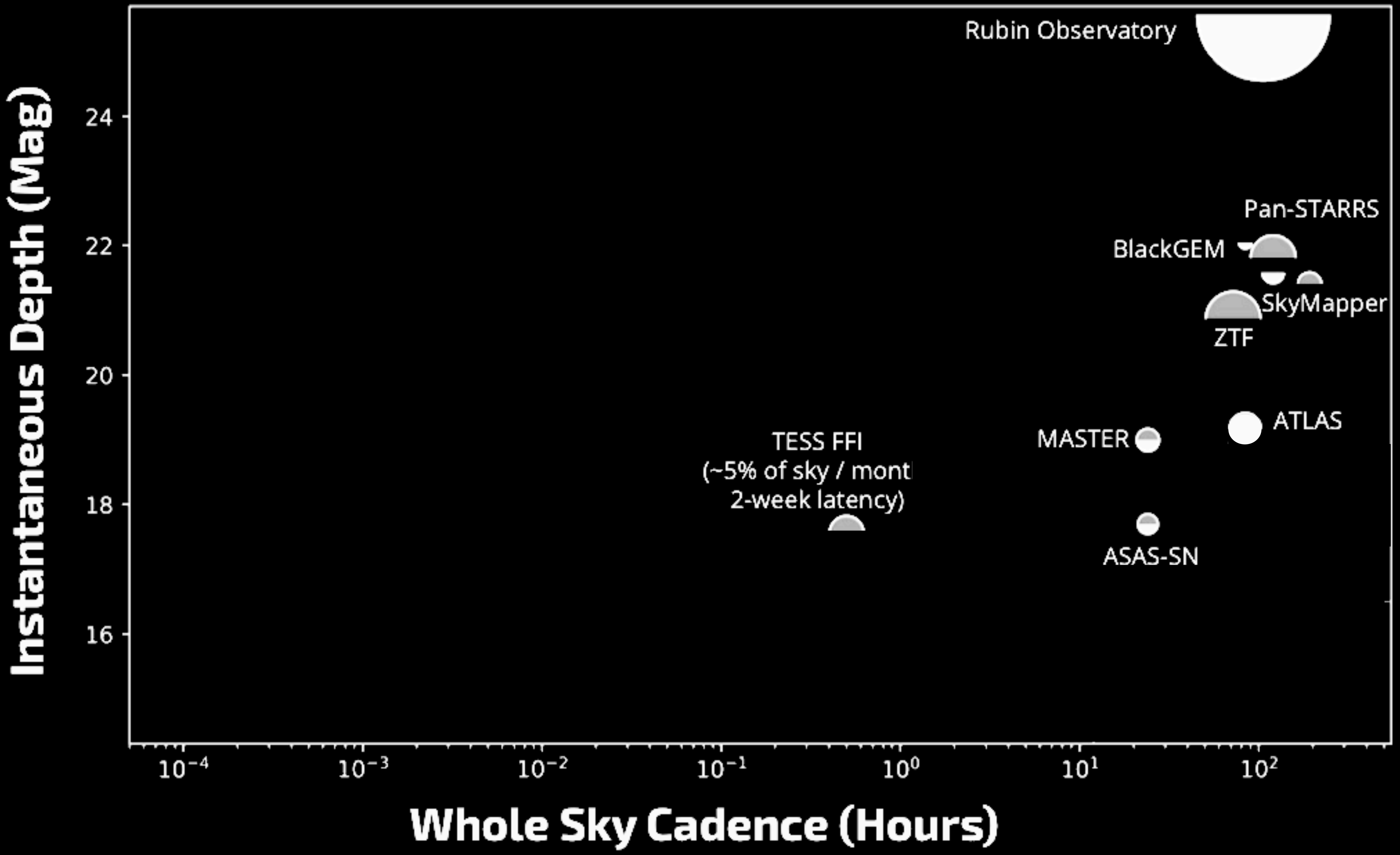
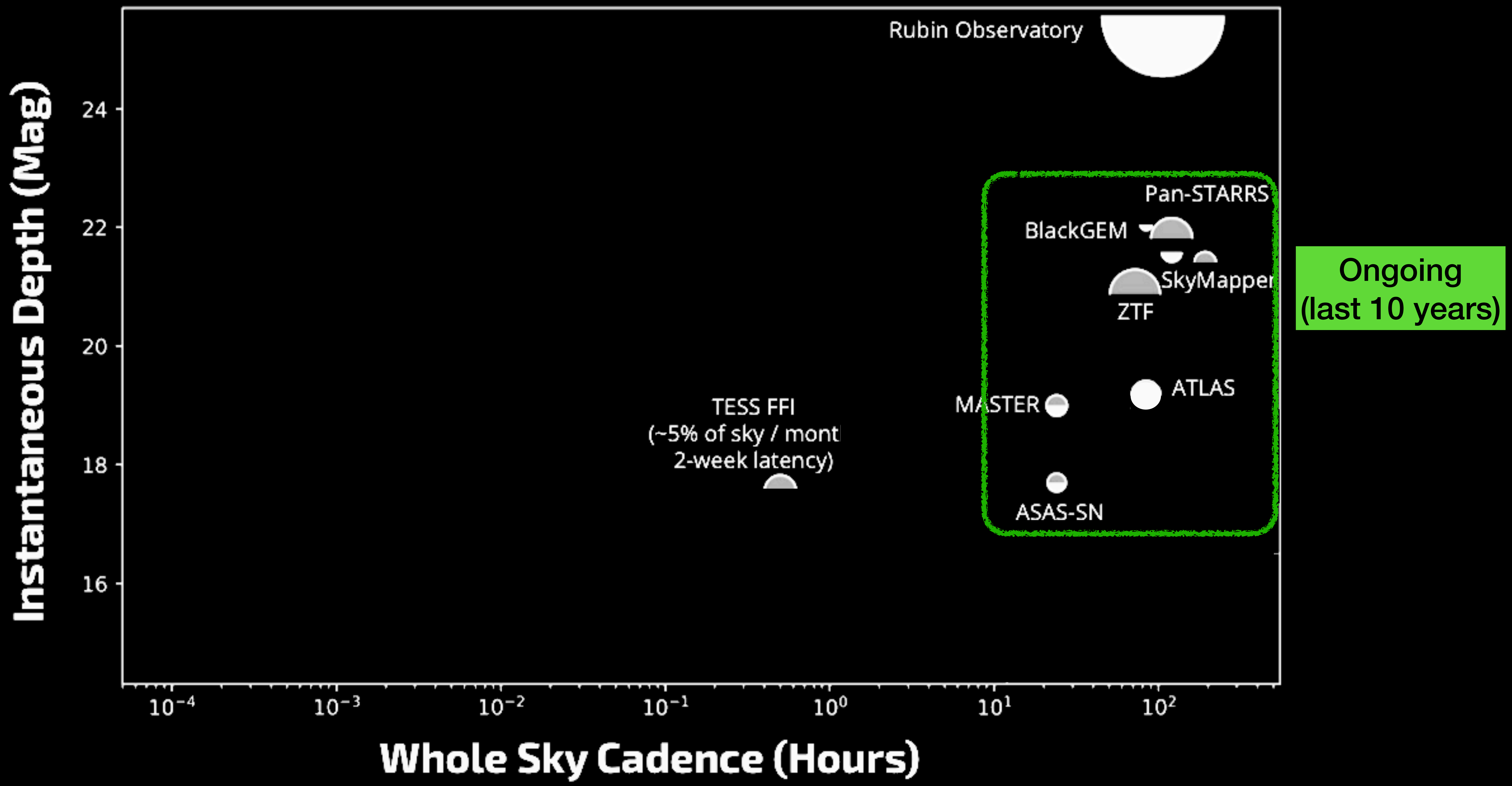


Figure: The Argus Array

Optical transient surveys



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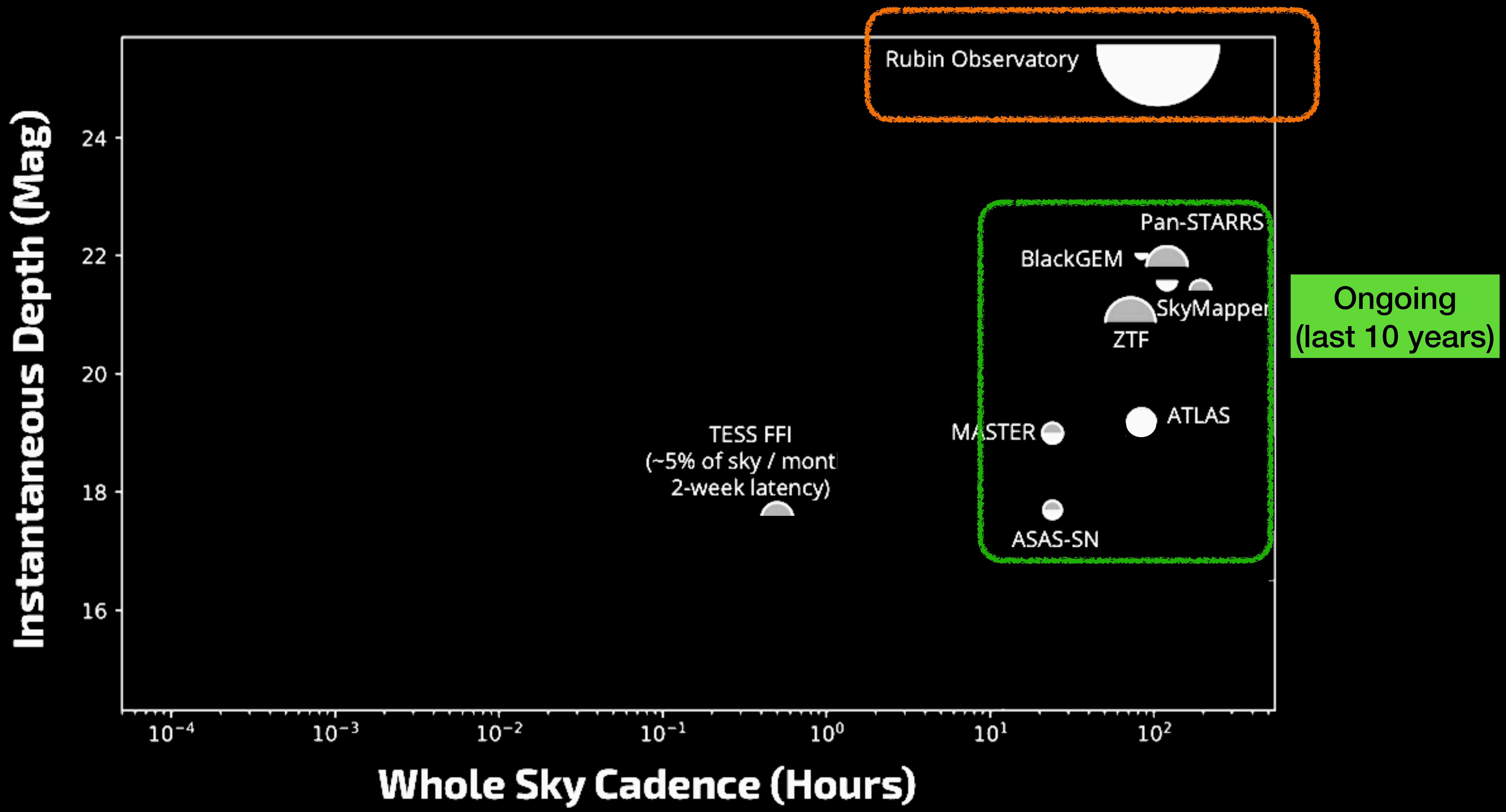

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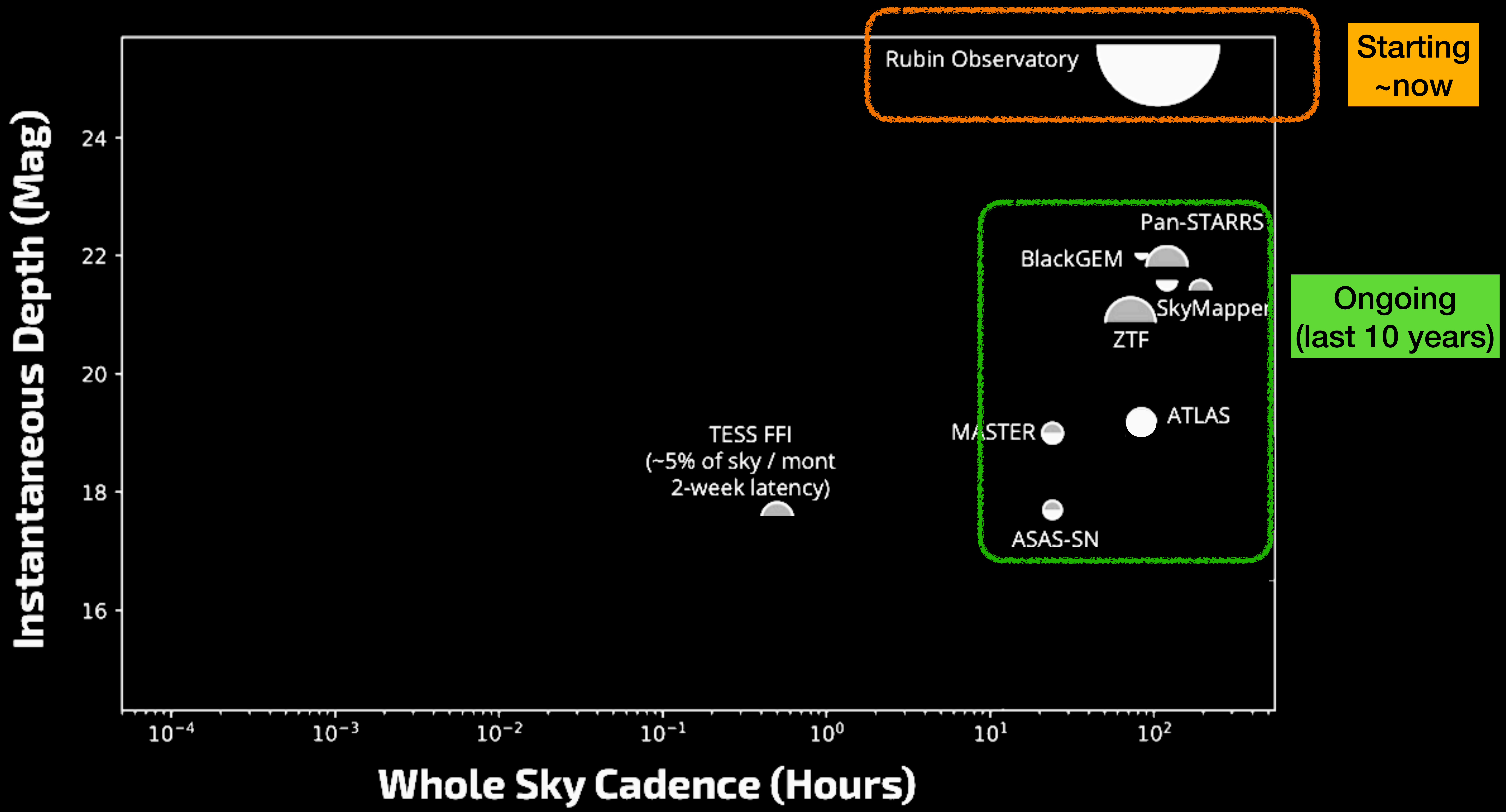

Figure: The Argus Array

Extraordinary detection rates

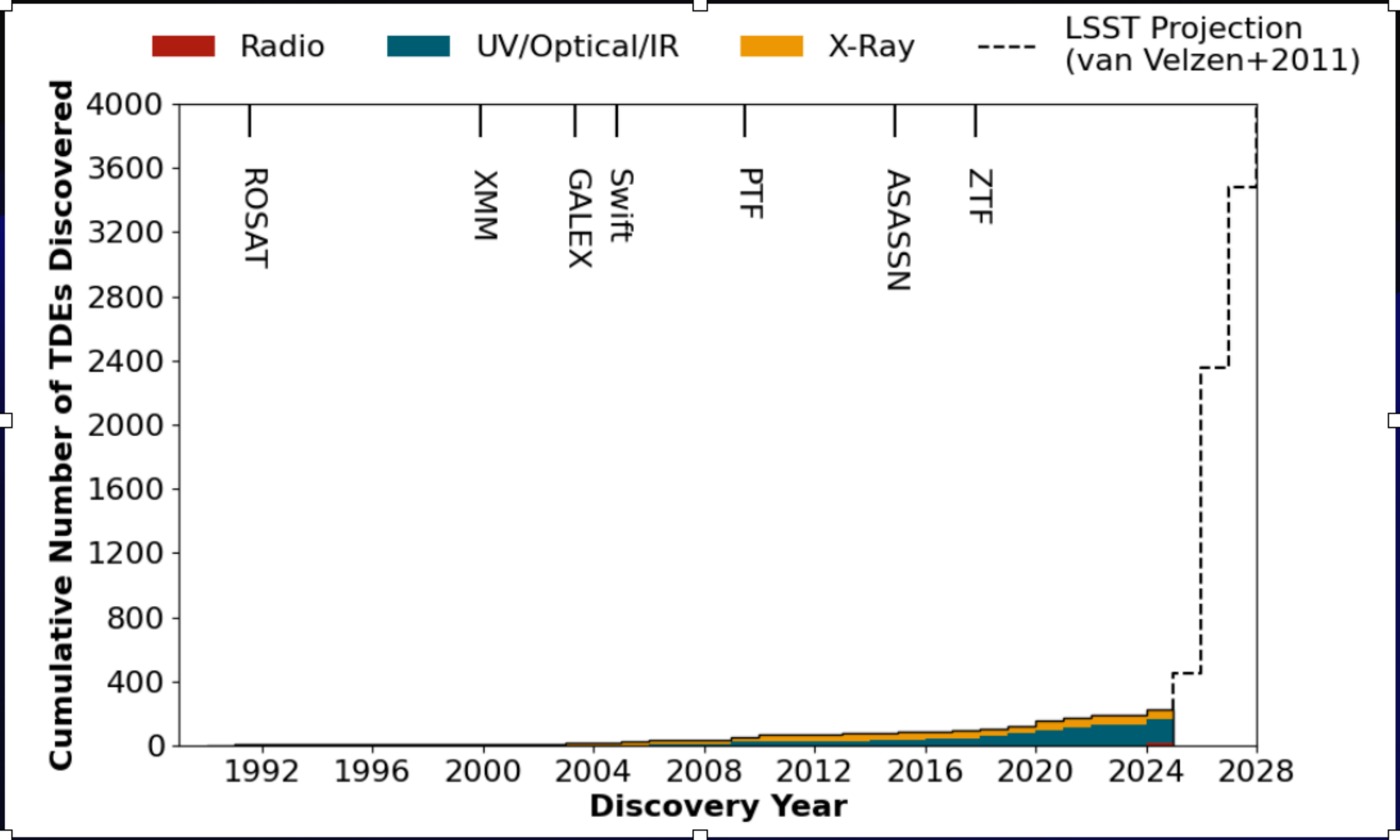

Image credit: N. Franz
(https://github.com/astro-otter/examples/blob/main/tde-discovery-histogram-linear.gif)

Vera C. Rubin Observatory

- Mirror: 8.4 m

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Vera C. Rubin Observatory
• Mirror: 8.4 m
• FoV: 9.6 deg²
• 6 bands (u, g, r, i, z, y)
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• 10M transient alerts per night
• ~1000 new supernovae per night

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Alert data is **public**,
provided via

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Alert data is **public**,
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Community Brokers

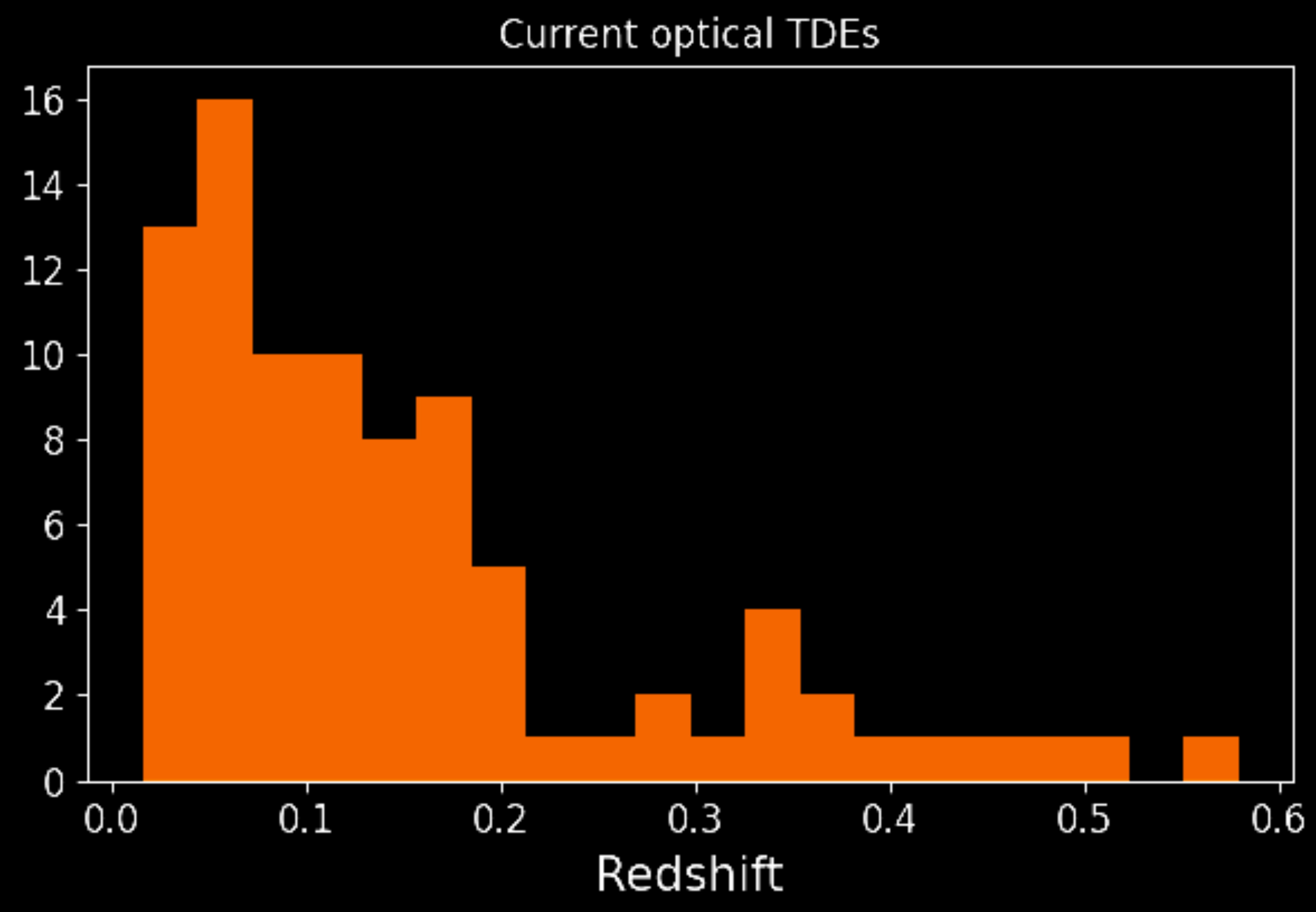
I coordinate the Rubin TDE group

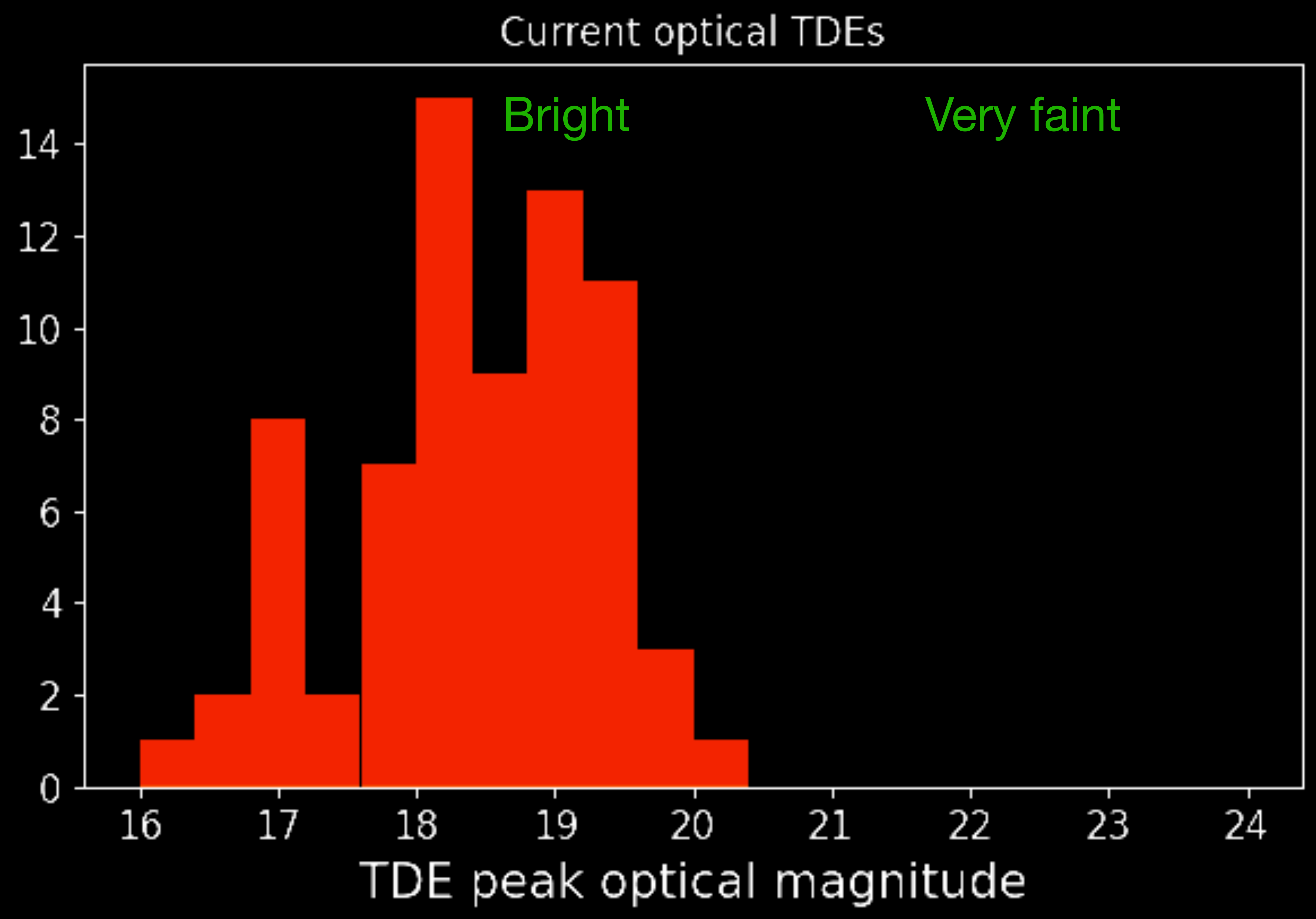
- Rubin will allow Target of Opportunity observations!
- Two types:
  - Gravitational Wave alerts (kilonova)
  - Neutrino alerts (any observatory)

Rubin first light image
(zoomed-in section; Virgo cluster)

Vera C. Rubin Observatory

Extraordinary classification challenge





Vera C. Rubin Observatory

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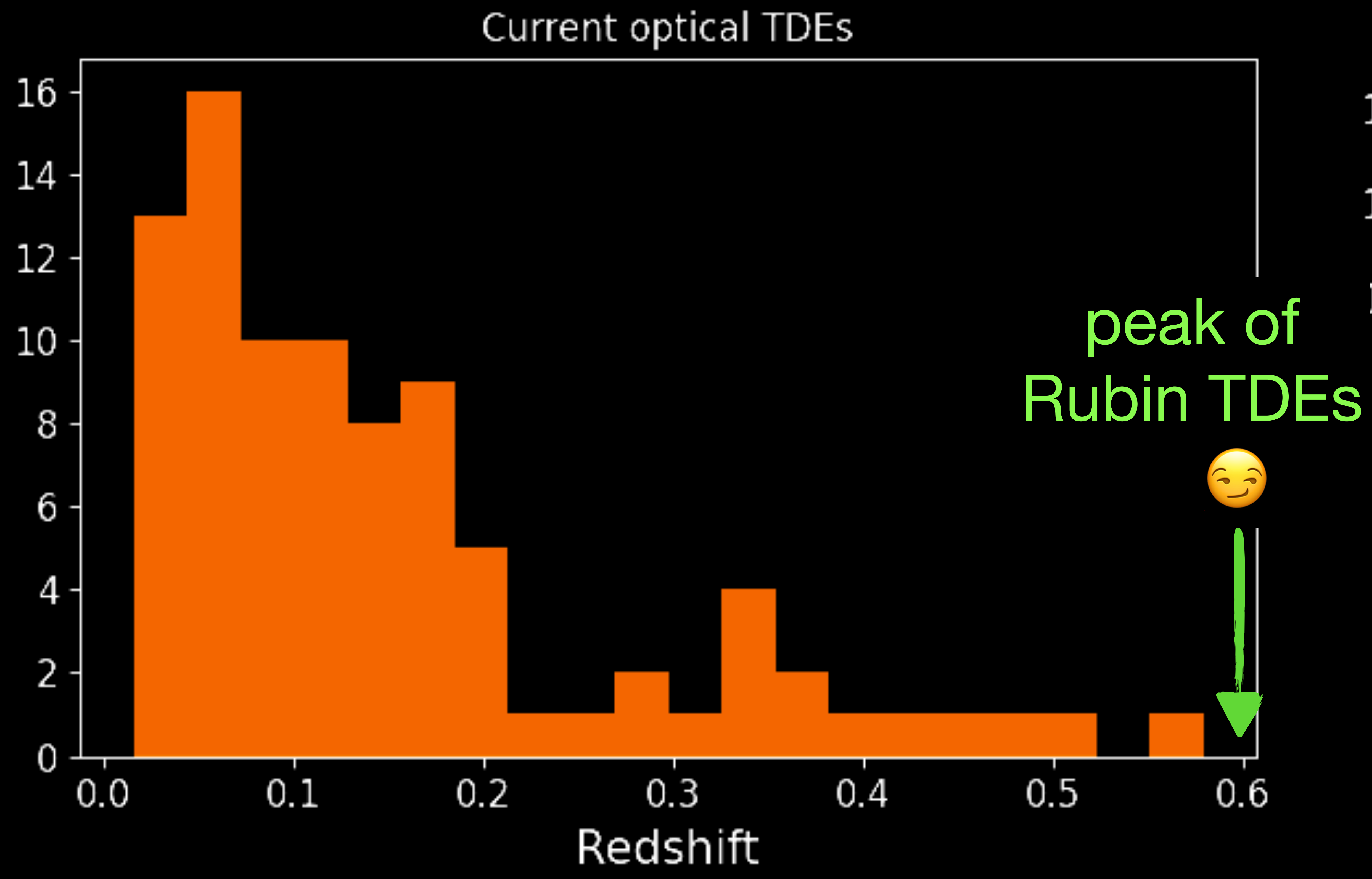

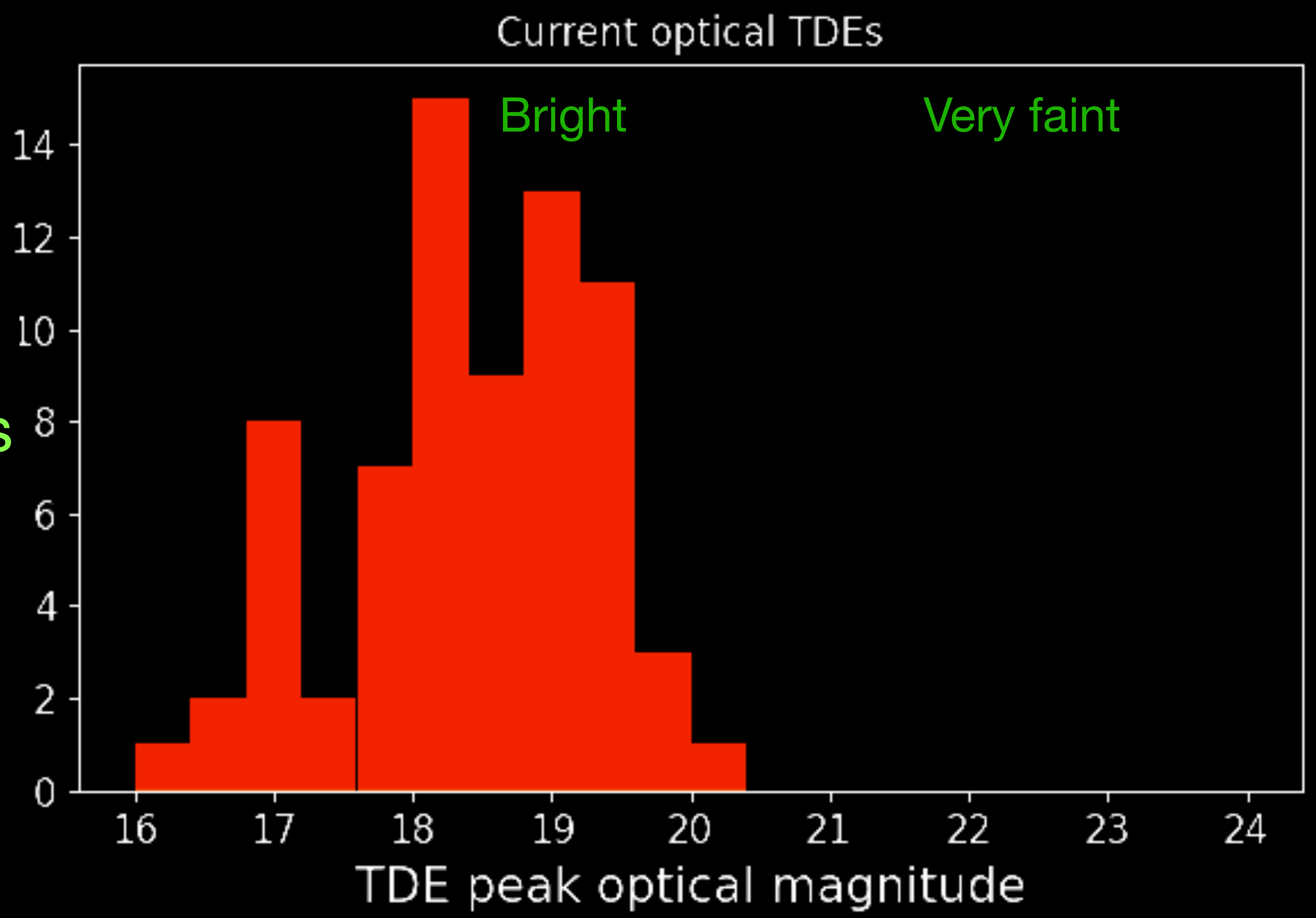

Vera C. Rubin Observatory

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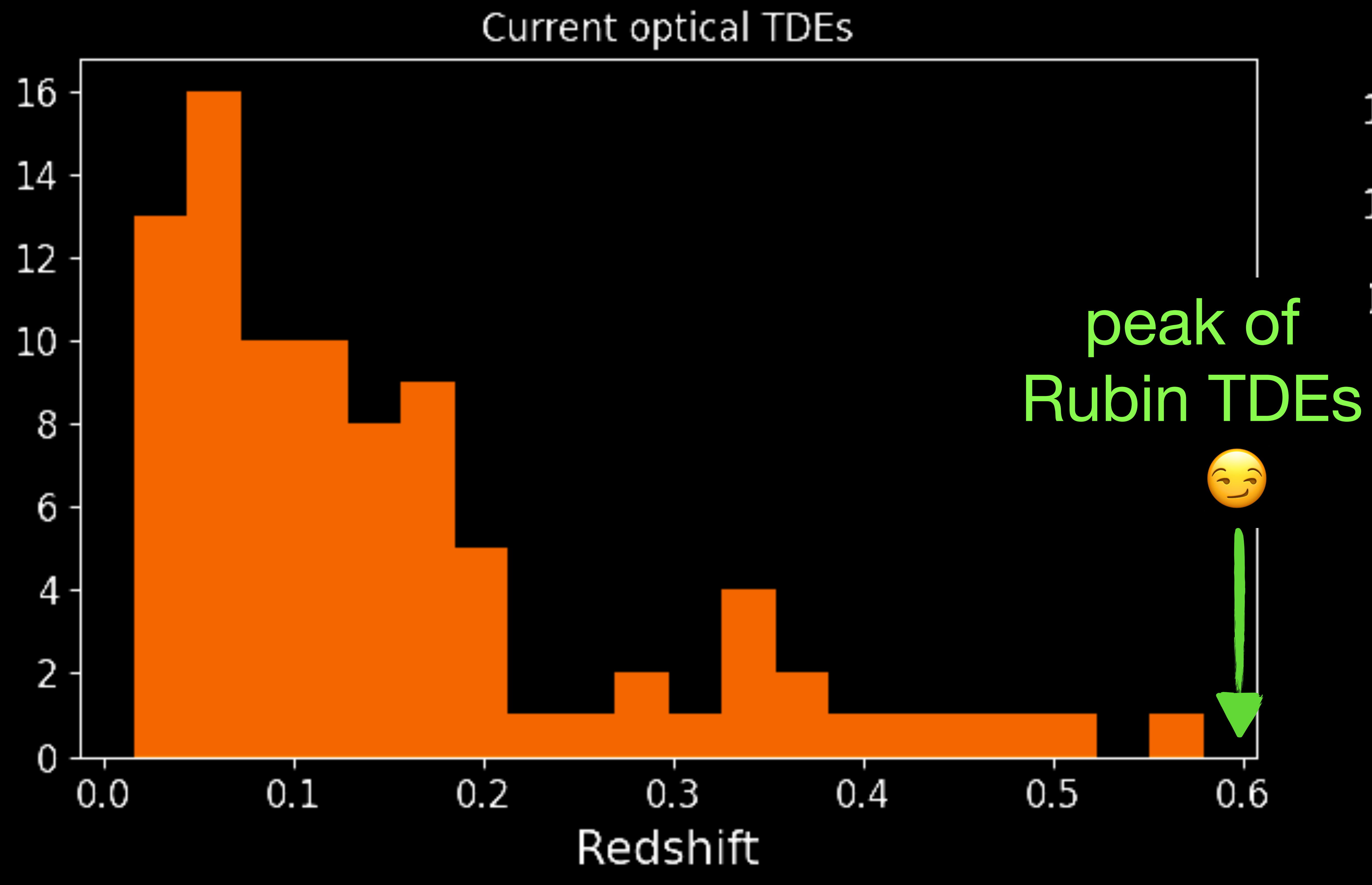
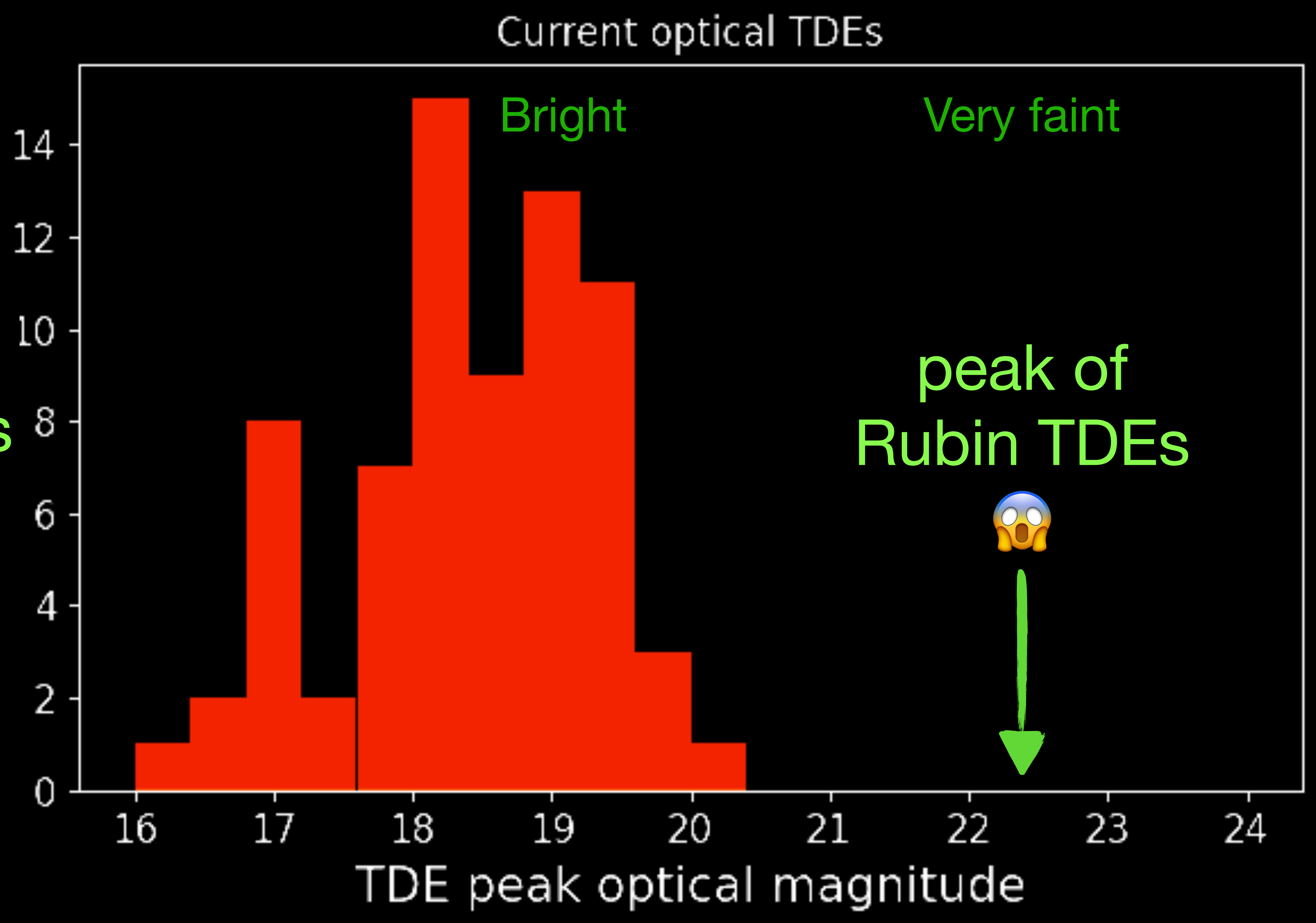
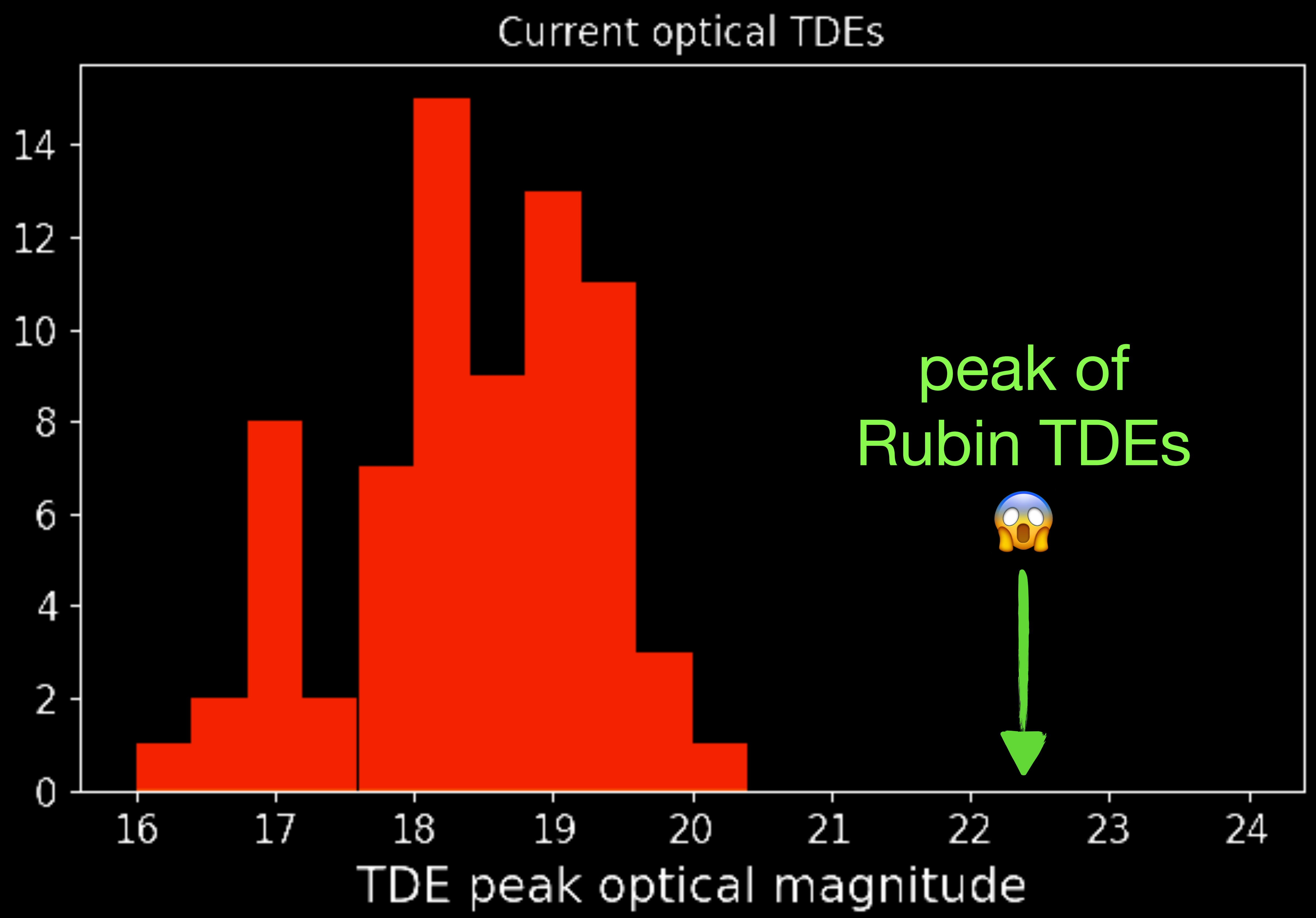




Vera C. Rubin Observatory

Extraordinary classification challenge

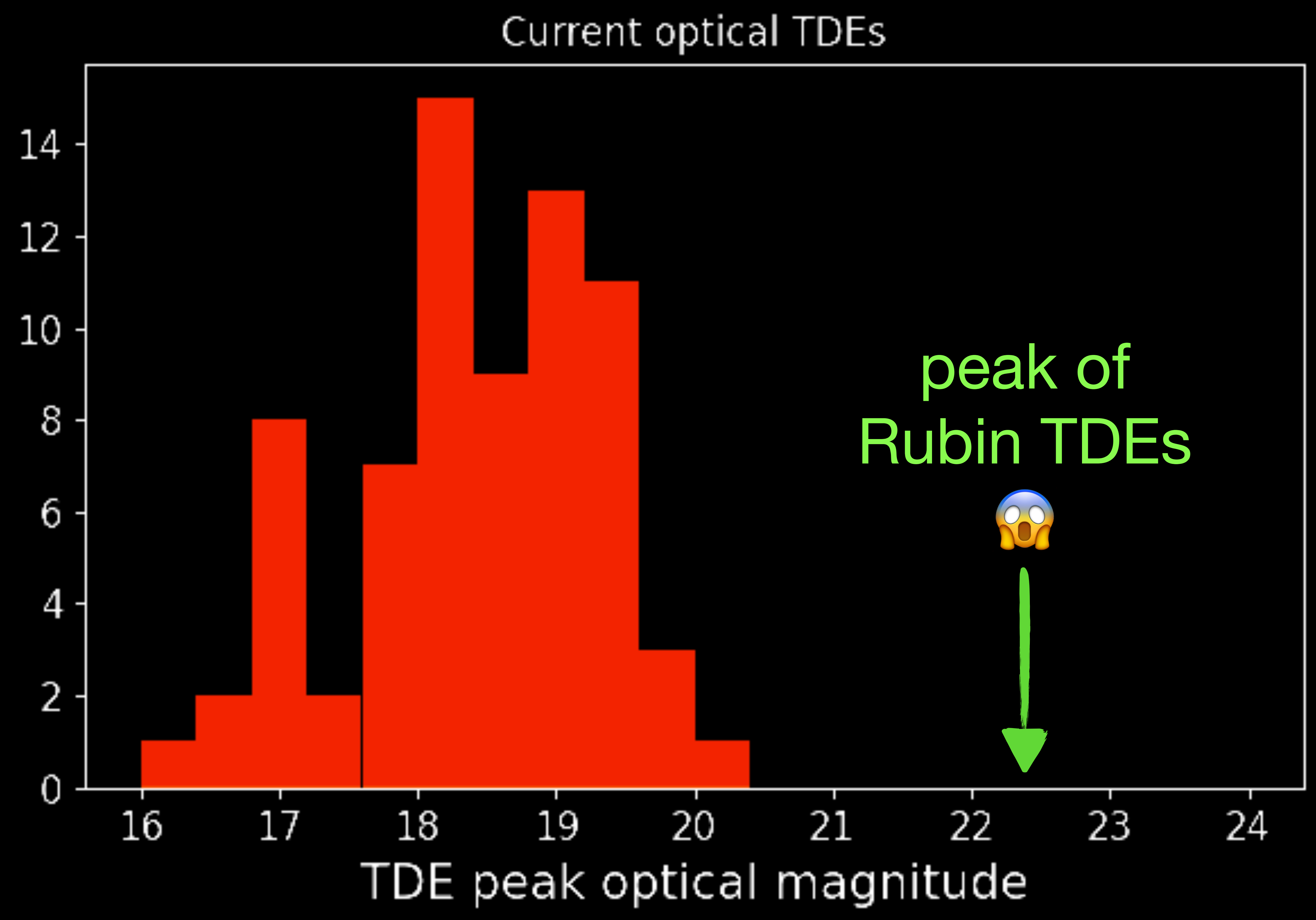
- Photometric classification required
  - Machine learning;
  - Need a training sample:
    - From simulations?
    - Of known TDEs?
    - Subset of Rubin data



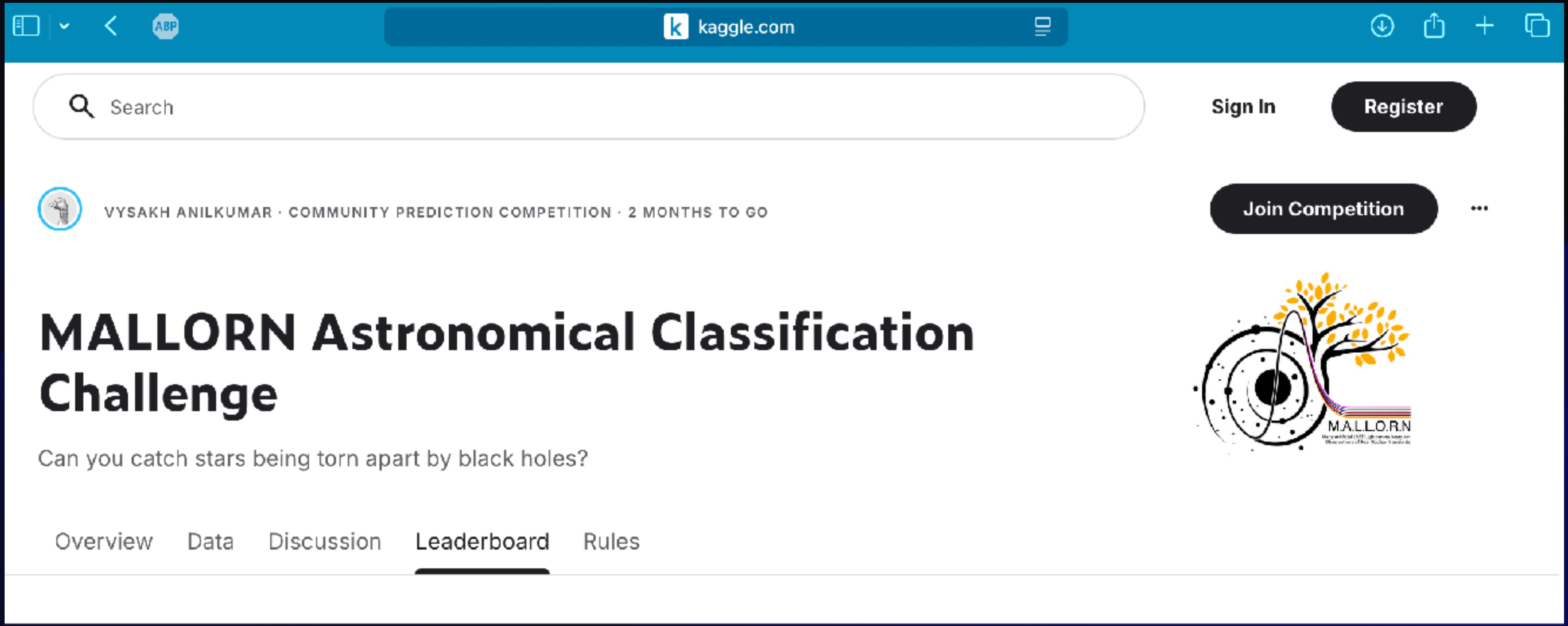
Vera C. Rubin Observatory

Limitations of photometric classification

- ML good at *finding what we already know*
- Most TDE properties were not predicted
  - ML Anomaly detection (eg, self-organizing maps, Isolation forests):
    - ML has yet* to detect something truly new
    - How to examine the anomaly if the transient has faded?



We are hosting a data challenge



61 entries on the leader board!;
mostly from outside astronomy!

Future facilitates at other wavelengths

- To keep up with Rubin
  - Factor 10 increase in sensitivity
  - For survey missions: all sky
  - For follow-up: can accept (lots of) triggers

Who can keep up with the Rubin Nuclear Transient rate?

WAVELENGTH	CURRENT	WITHIN 5 YEARS	KEEP UP WITH RUBIN?

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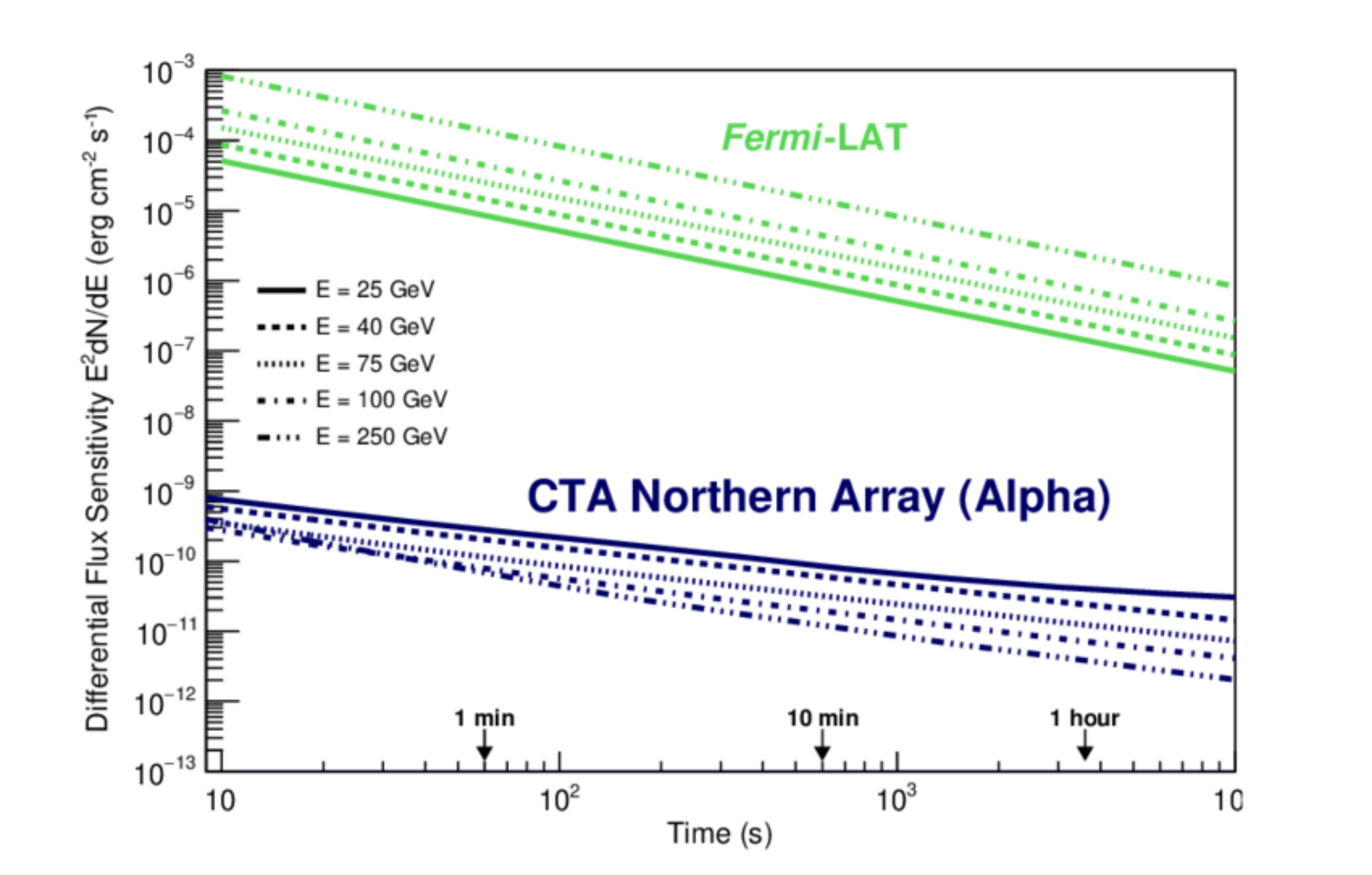
Infrared	NEOWISE, JWST	NEO Surveyor (2027)	NO
Radio	VLA, AMI, ALMA, EVN, ATCA, GMRT		NO

~10-100 GeV transients with CTA



Who can keep up with the Rubin Nuclear Transient rate?

WAVELENGTH	CURRENT	2030-2040	KEEP UP WITH RUBIN?

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WAVELENGTH	CURRENT	2030-2040	KEEP UP WITH RUBIN?
UV	Swift, HST, svom	UVEX (2030)	YES

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X-ray	Swift, Chandra, XMM, NUSTAR, NICER, IXPE, Fermi, Einstein Probe, SVOM	eXTP, CATCH, AXIS, THESEUS, ATHENA	YES

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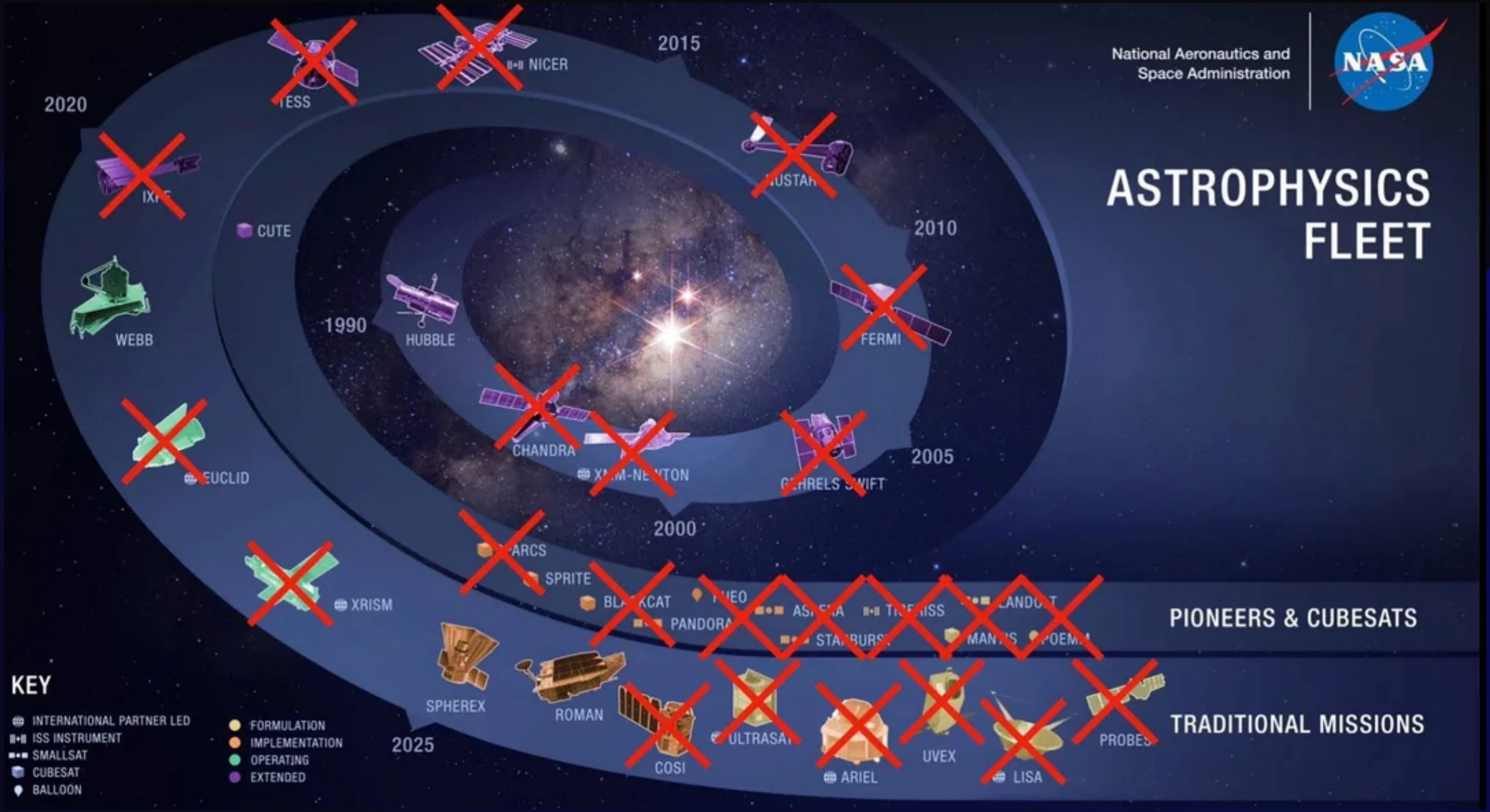
Infrared	NEOWISE, JWST		
Radio	VLA, AMI, ALMA, EVN, ATCA, GMRT	SKA-mid, ngVLA, DSA-2000, FAST-core-array	YES

Budget nightmares



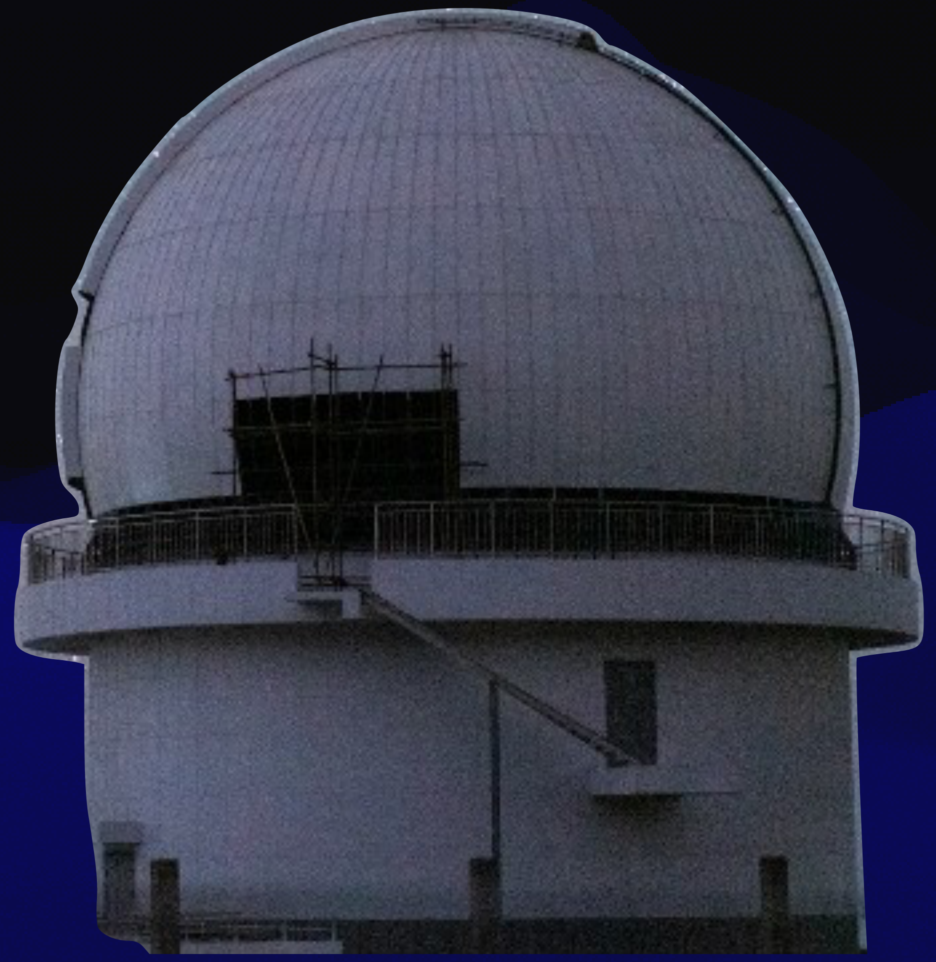
Disclaimer:
image from Reddit

New deadline for US budgets is Jan 30

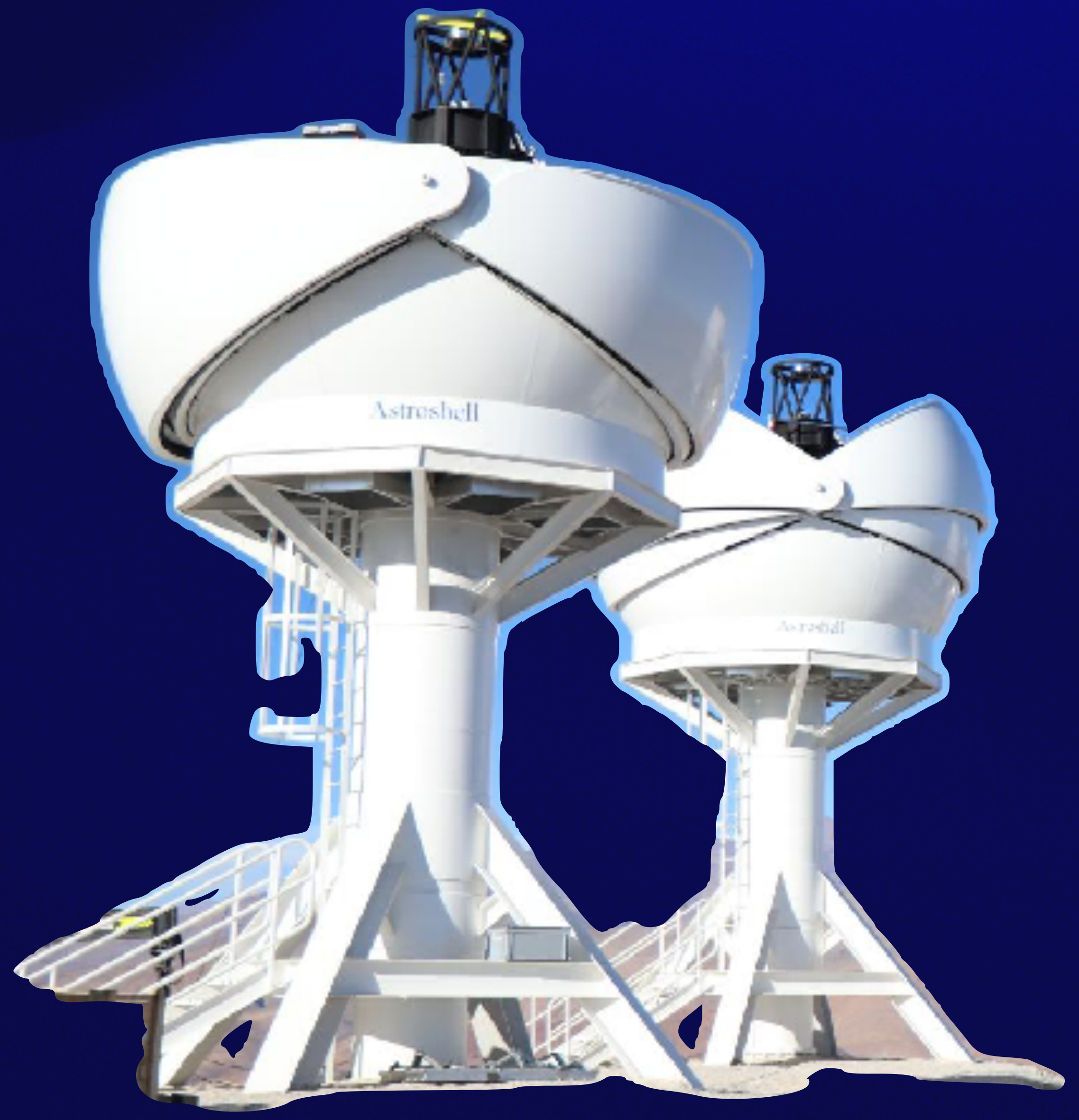
More optical observatories

- Chinese Space Station Telescope (Xuntian; December 2026)
- Plato (2026)
- Ground-based specialists:
  - Now: ASAS-SN, ZTF, ATLAS, PS1, **BlackGEM**, WINTER, **LS4**, **WFST** …
  - Future: Argus Array, and more

LS4

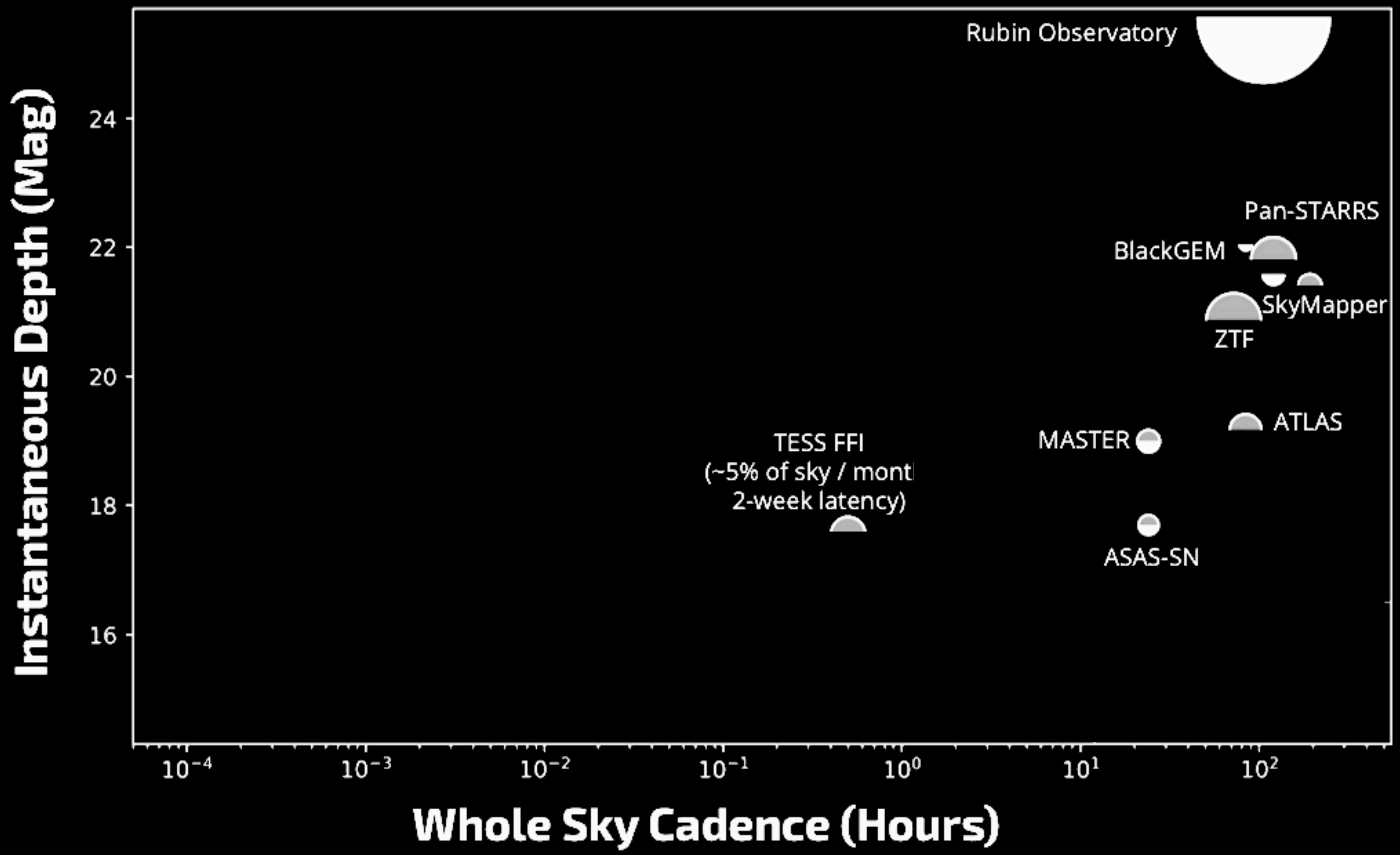


WFST



BlackGEM

What's hiding in the dark?



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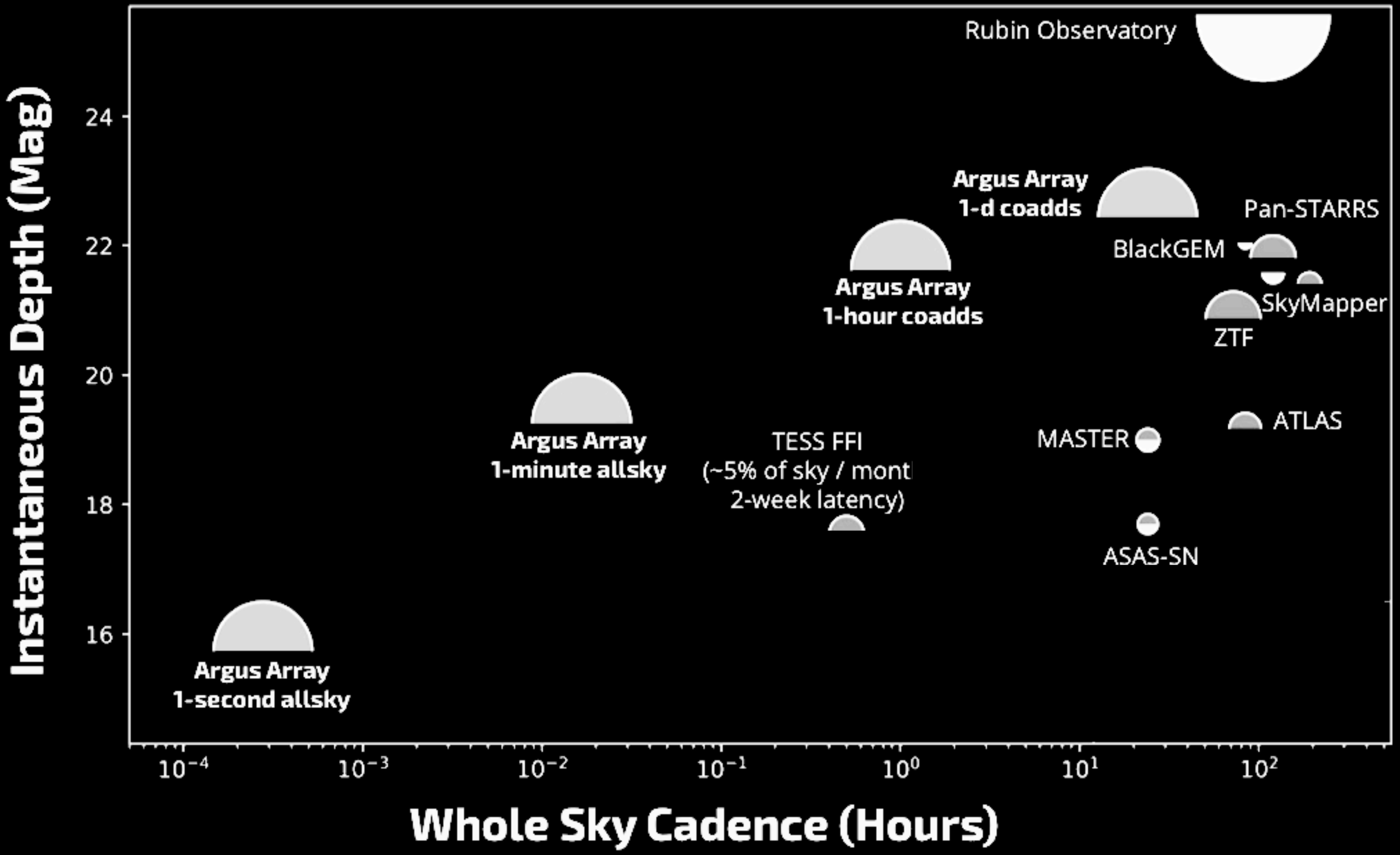

Conclusions / predictions

Valid up to 2030

- Rubin: Factor 10 increase in photometric events
  - Large samples via ML
  - Spectroscopic follow-up limited
  - Reliance on simulations for training ML
- Detection rate of transients with extensive multi-wavelength coverage:
  - Will not significantly increase
  - Could drastically decrease (budget cuts)
- New discovery potential:
  - New messengers/wavelengths (CTA, neutrinos)
  - Shorter timescales

Roman Space Telescope

Launch 2027?

- Conduct two time-domain surveys:
  - Very deep near-IR (m~25);
  - 10-30 sq. deg
  - 150 epochs over 2 years
  - Main science goal: $\sim 10^4$ SNe Ia at z~1-2
    - 10^2 TDEs at these redshifts!
    - Again, photometric classification only
  - Lots of hot dust transients!