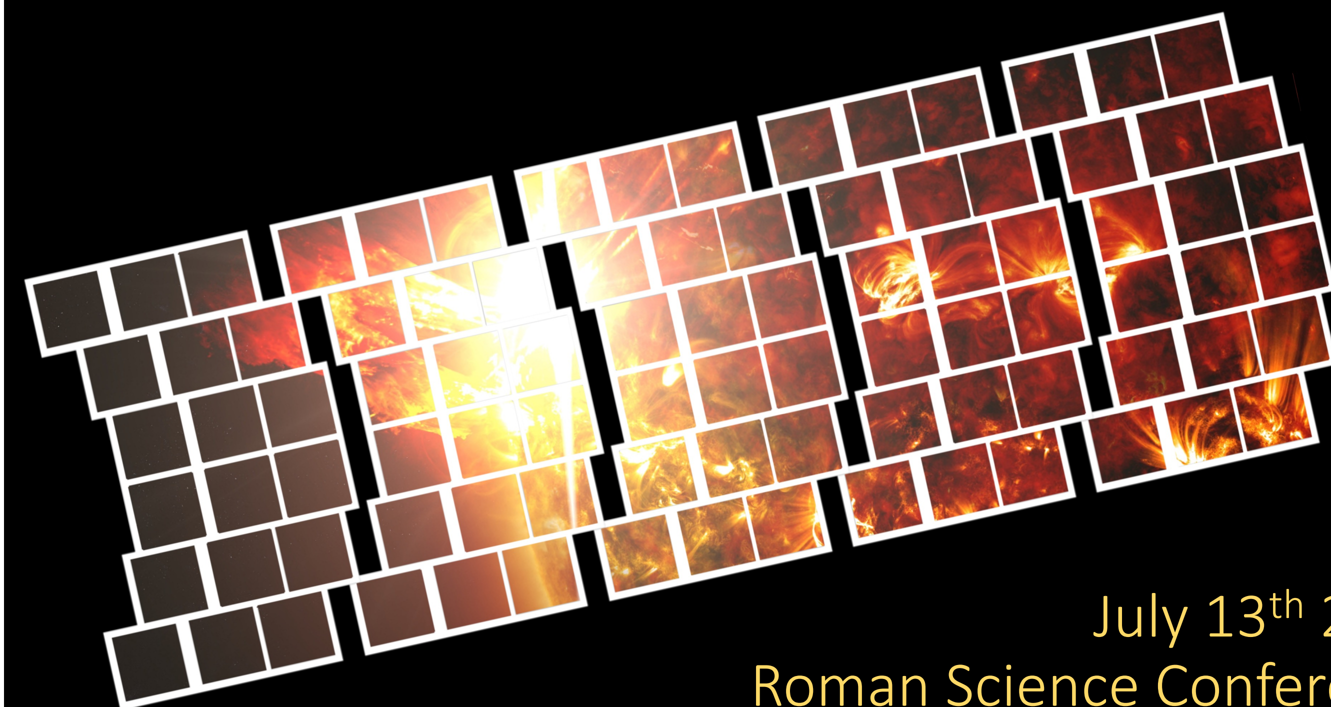
Surveying stellar flare rates and properties in a new wavelength regime with the GBTDS



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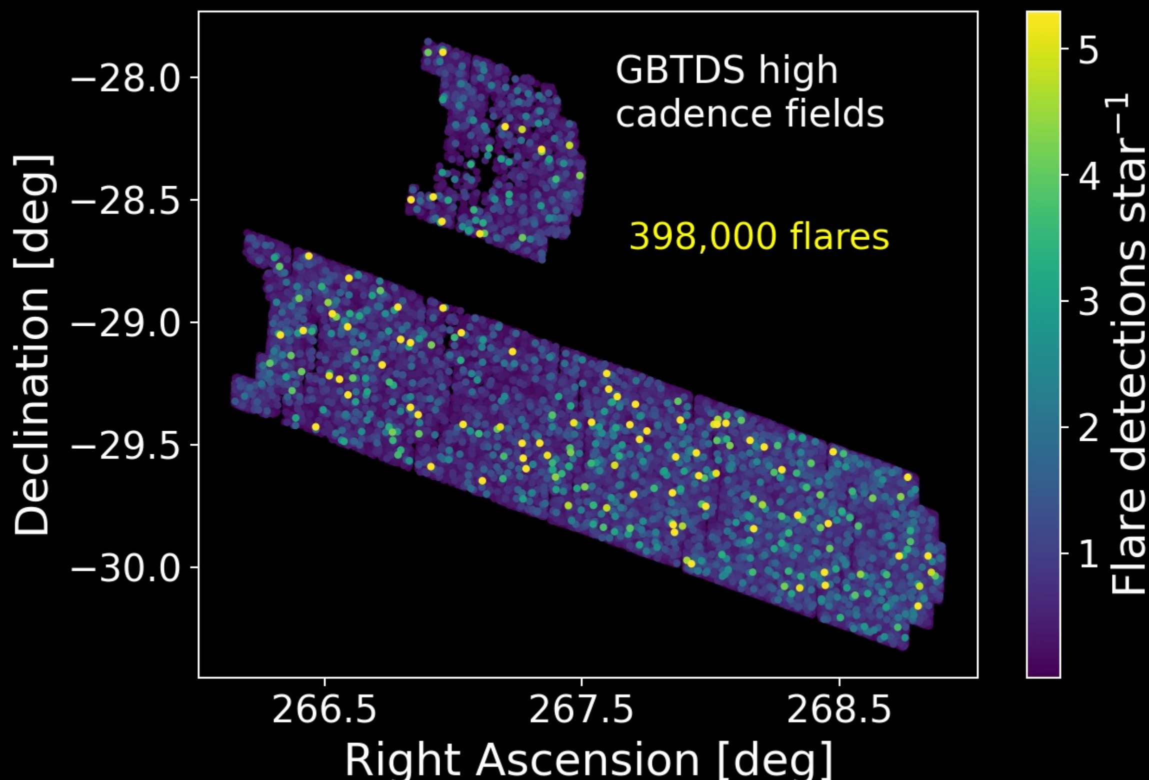
Meredith MacGregor (JHU)

July 13th 2026
Roman Science Conference

Roman will enable the first population-level analysis of infrared flares



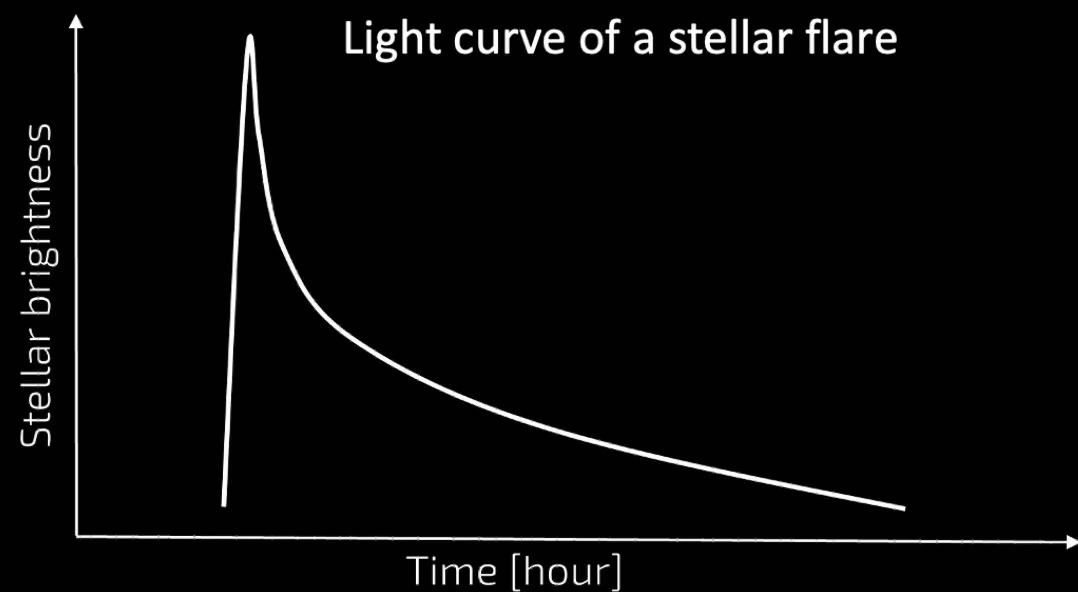
Infrared flares are poorly understood due to their stochastic occurrence, short timescales, and low fluxes

Roman is the only facility capable of obtaining robust statistics on IR flare rates and properties as functions of stellar mass and age

Our Cycle 1 GO 19104 program (PI: Howard) funds us to carry out this survey!

What is a solar or stellar flare?

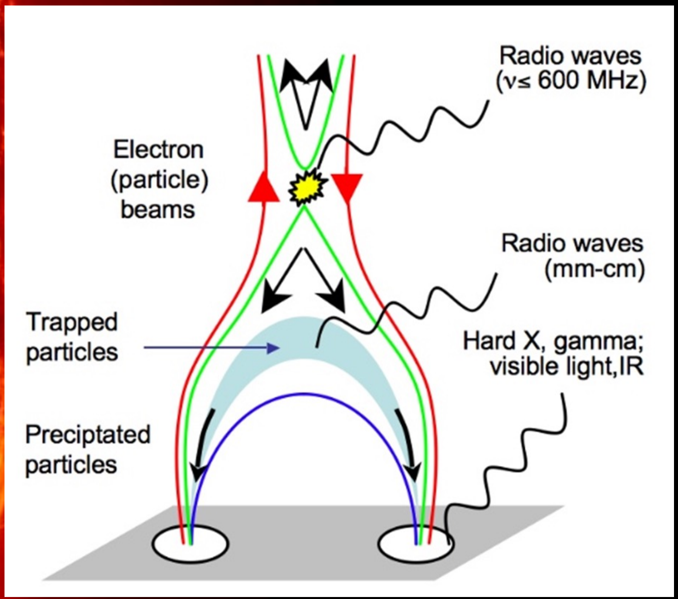
Flares occur when magnetic reconnection accelerates charged particles down field lines toward the star, heating the plasma



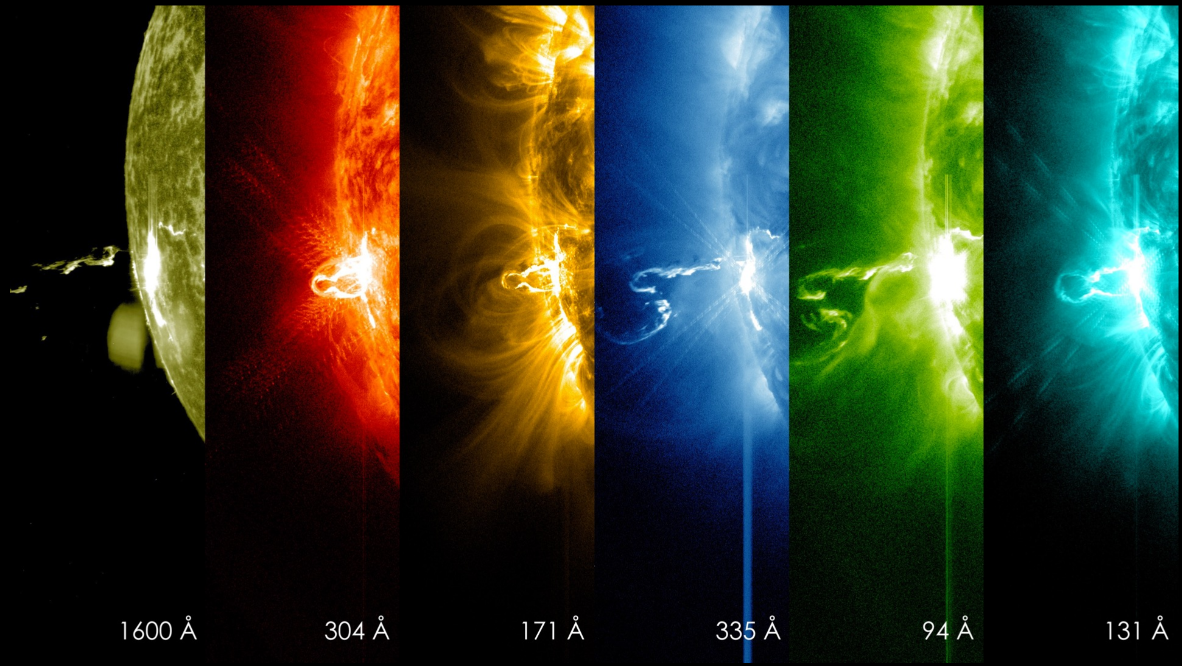
Stars flare across the electromagnetic spectrum

No single observation (at any wavelength) can give us a complete picture of the physics at work or the energies produced during a flare

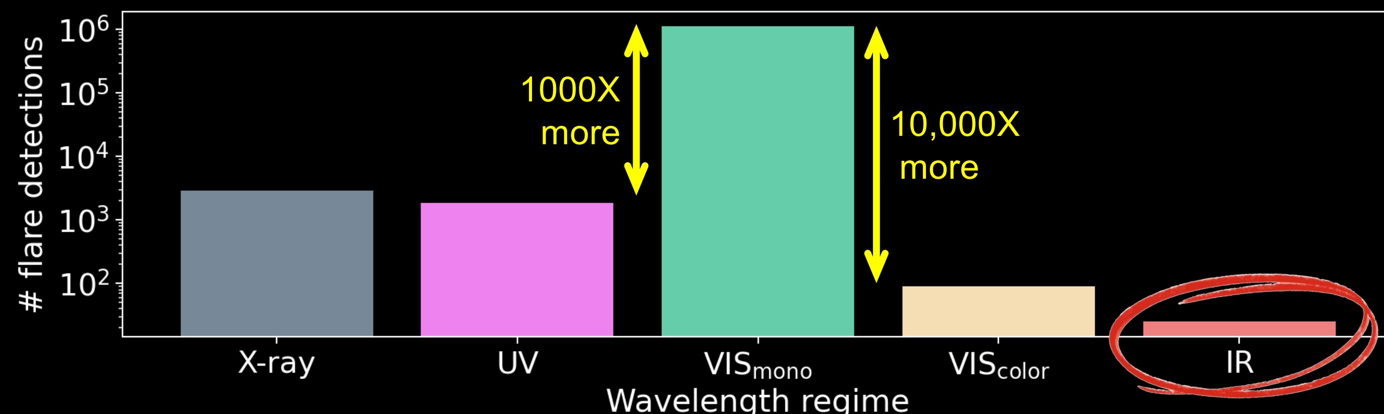
We need observations across the spectrum to better understand stellar flares!



Klein & Dalla (2017), SSR 212, 1107



The infrared is the least-studied regime in the landscape of statistical flare surveys

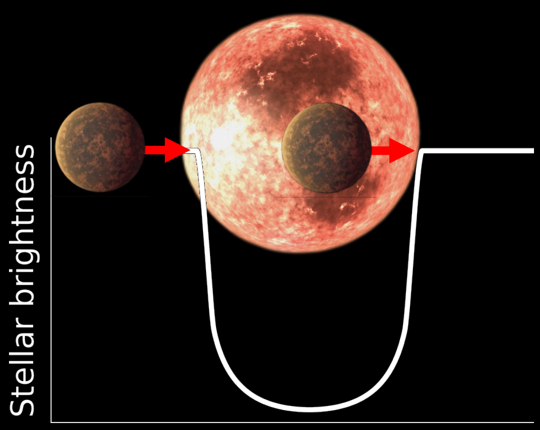


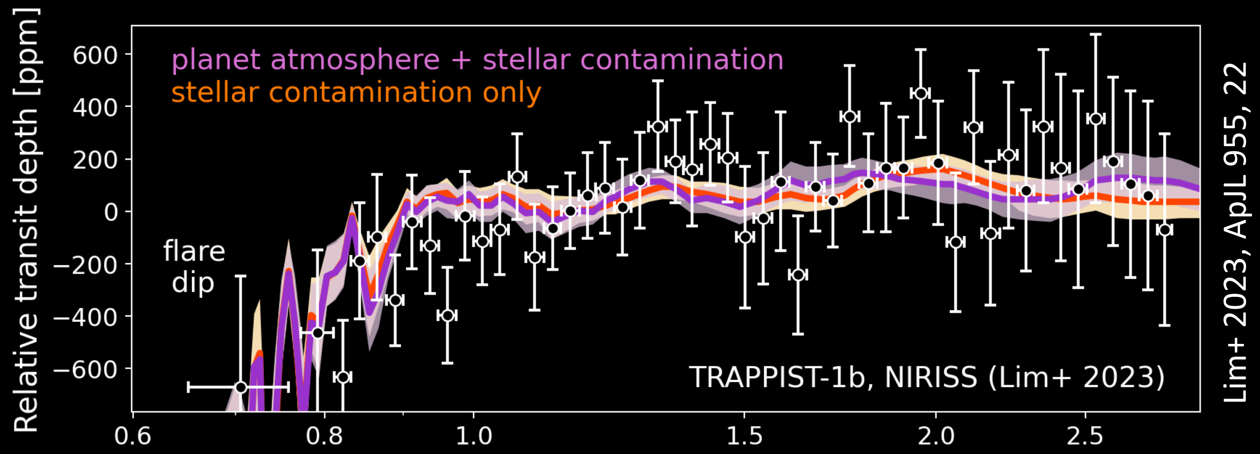
X-ray surveys: Getman+ 2021, ApJ 916, 32; Zhao+ 2024, ApJ 961, 130; Pasquato+ 2026, A&A in press **UV surveys**: Brasseur+ 2019, ApJ 883, 88; Loyd+ 2018, ApJ 867, 71; Paudel+ 2024, ApJ 971, 24 **VIS_{mono} surveys**: Yang+ 2019, ApJS 241, 29; Feinstein+ 2022, ApJL 925, 9 **VIS_{color} surveys**: Kowalski+ 2013, ApJS 207, 15; **Howard**+ 2020, ApJ 902, 115 **IR surveys**: Ducrot+ 2020, **Howard**+ 2025, ApJL 994,31; Allen+ 2026, AJ 171, 105

What physics are we missing out on?

Unknown properties of infrared flares frustrate exoplanet transmission spectroscopy

Stellar signals imprint on the planet's spectrum via the **transit light source effect**

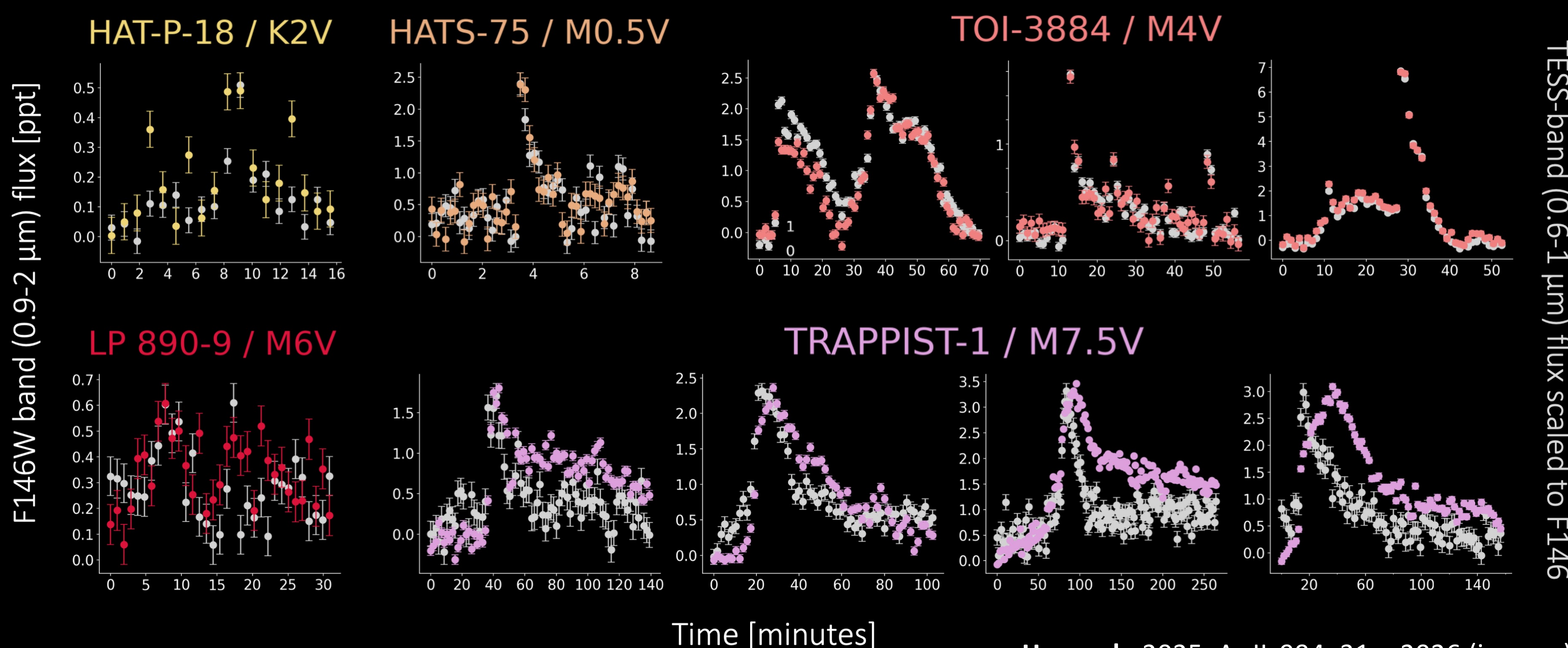




Contaminating flare signals are often 5-10X larger than planet atmospheric signals!

What we *do* know about IR flares comes mostly from JWST time series observations

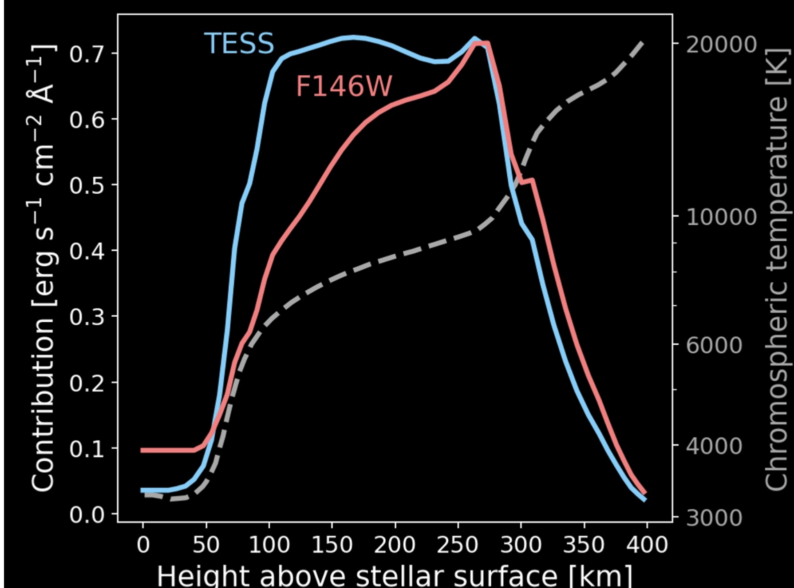
Dozens of flares from a handful of stars of various masses and ages have been recorded by JWST, primarily with NIRISS (0.6-2.8 μm) and NIRSpec (0.6-5 μm)



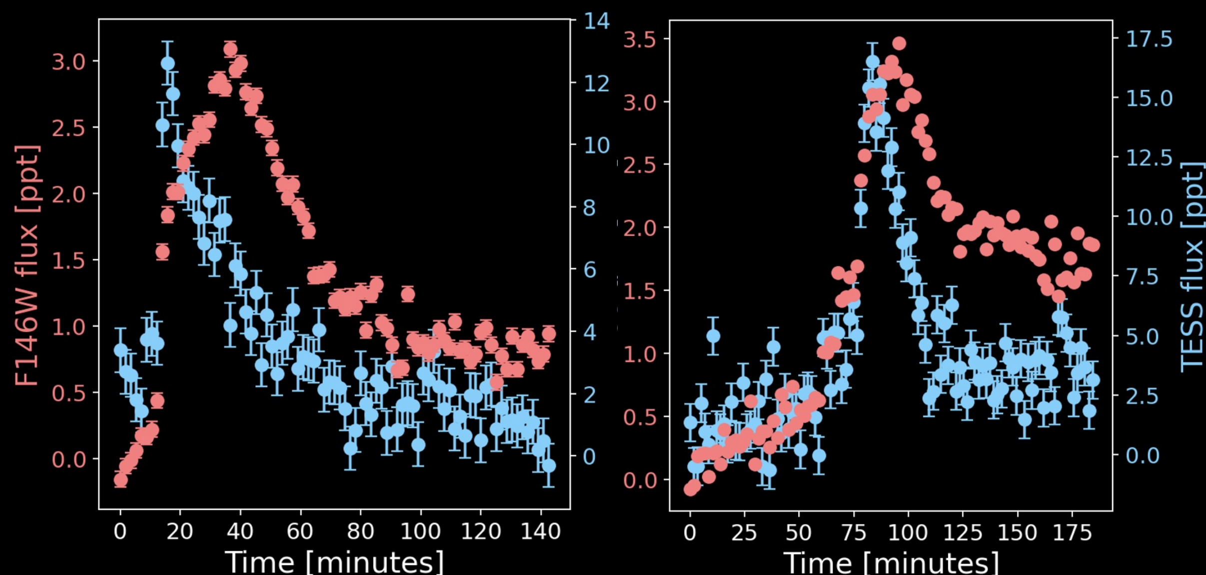
Howard+ 2025, ApJL 994, 31; +2026 (in prep)

What we *do* know about IR flares comes mostly from JWST time series observations

Convolving JWST spectral timeseries with TESS and F146 bands shows infrared light curves reflect different conditions in the stellar atmosphere than do TESS light curves



RADYN model; Kowalski+ 2024, ApJ 969, 121

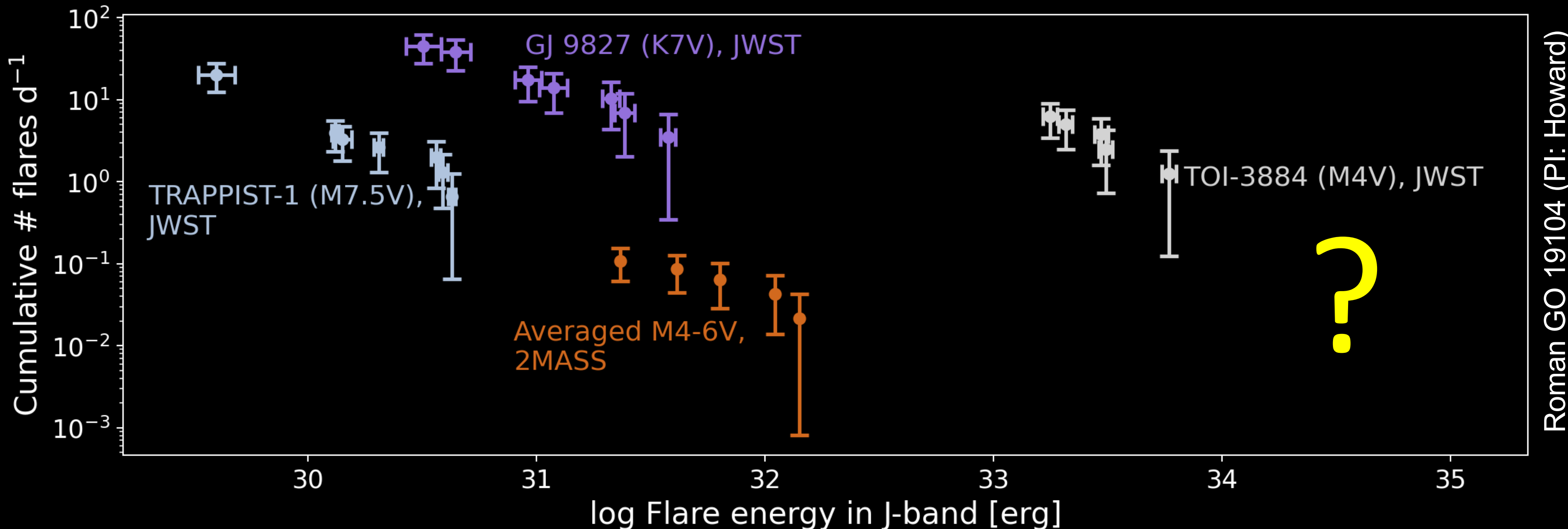


Actual data; **Howard**+ 2025, ApJ Letters 994, 31

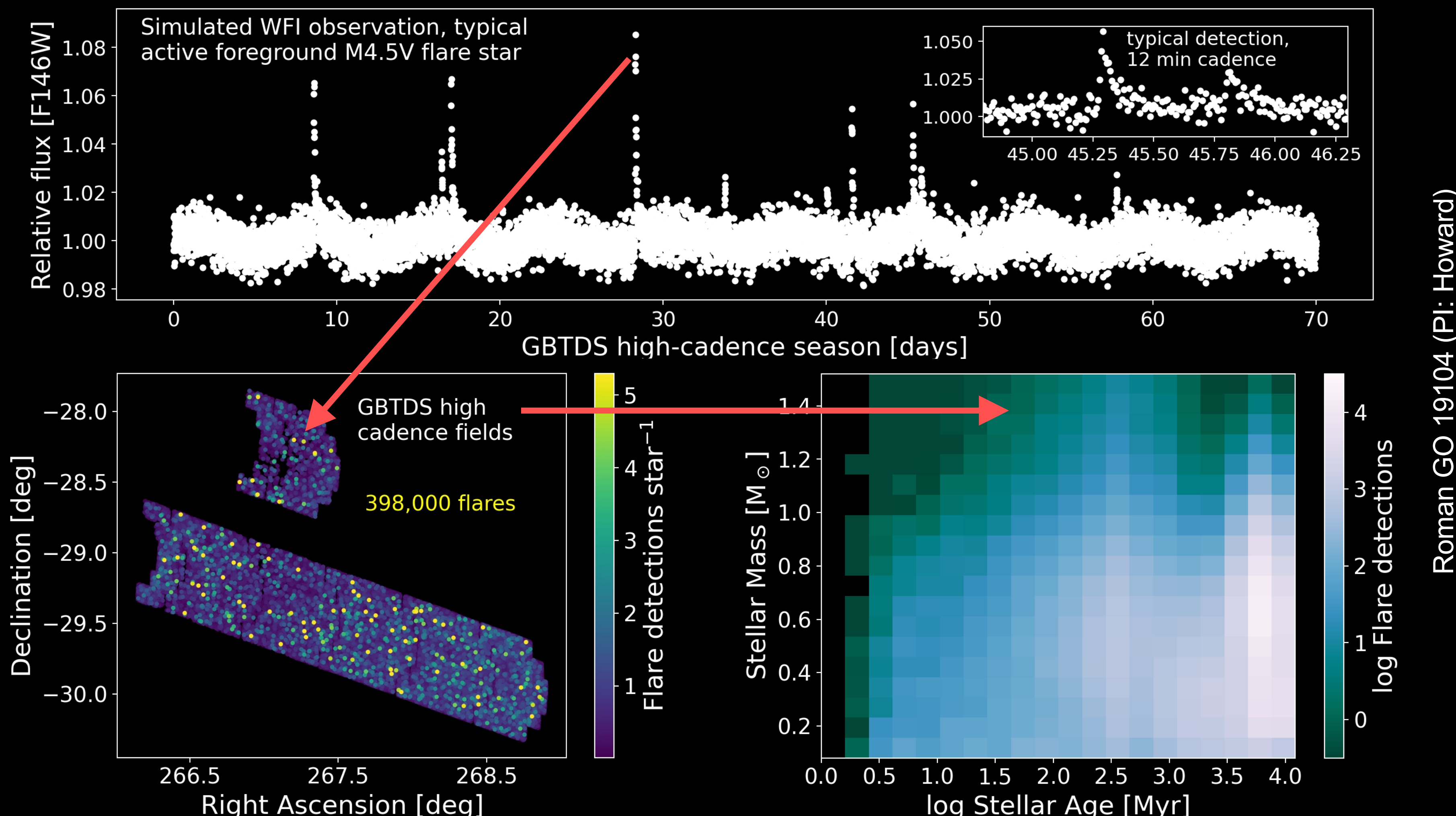
What we *do* know about IR flares comes mostly from JWST time series observations

Flare rates have been measured for only a handful of stars with JWST data.

"Typical" rates, as well as rates of the largest/rarest events remain unconstrained



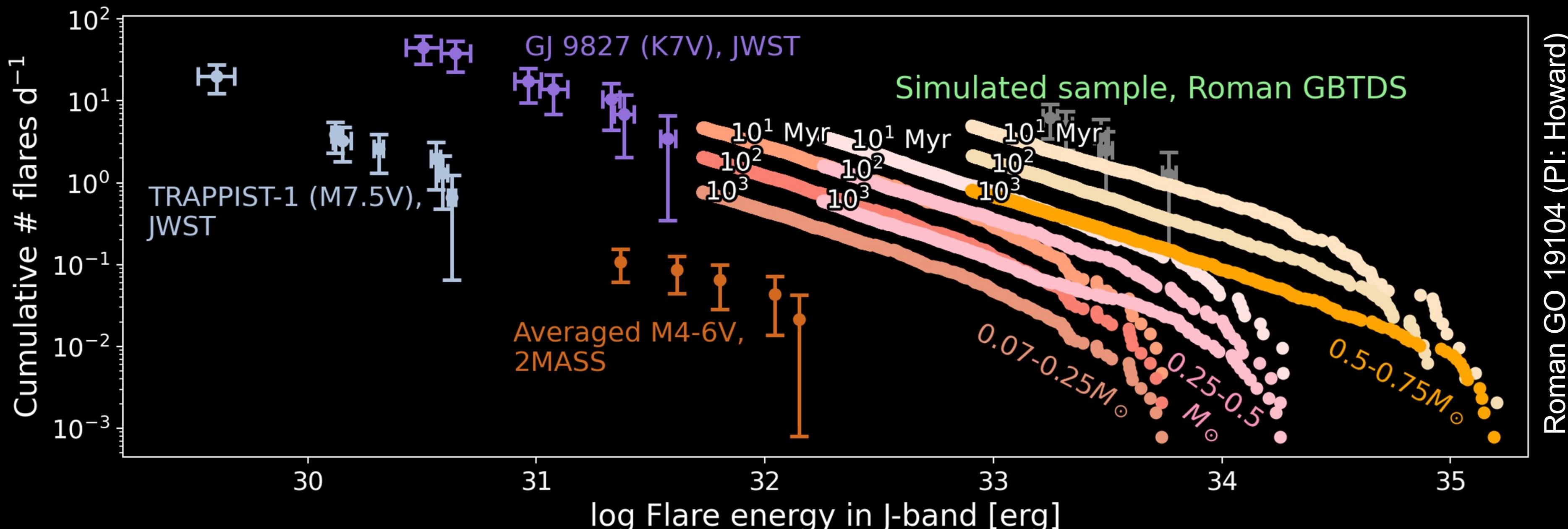
A thousandfold improvement in the number of infrared flares with Roman



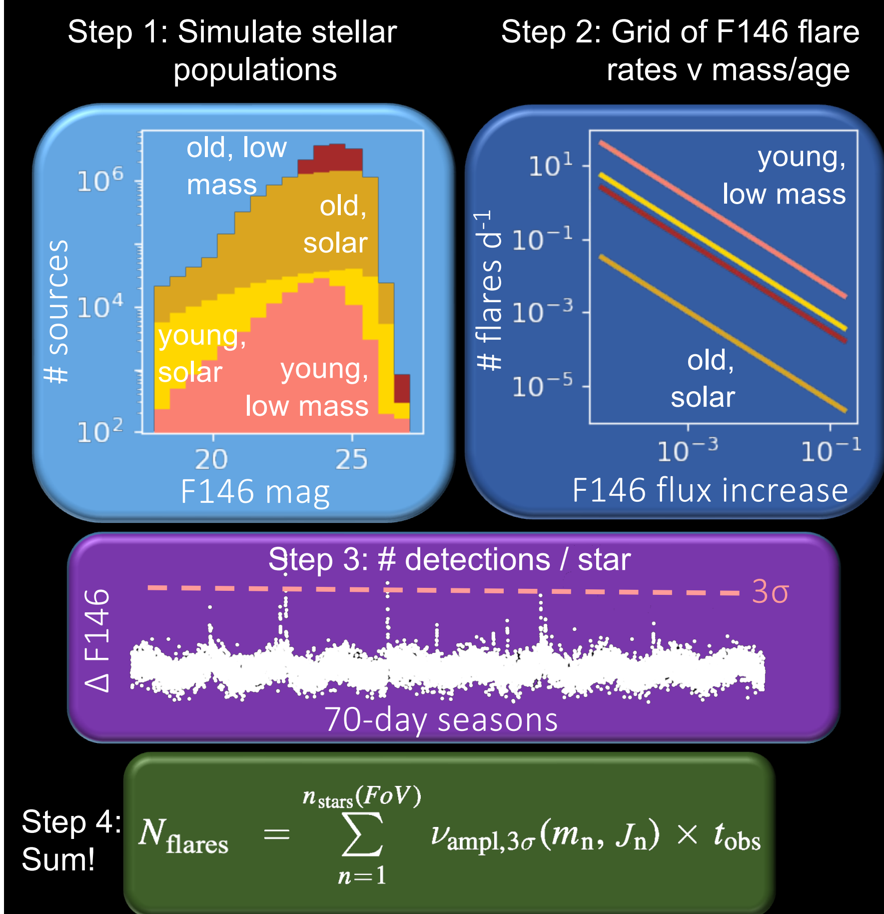
JWST and Roman observe complementary regions of the flare frequency distribution

JWST is most sensitive to frequently occurring “small” flares, but Roman is sensitive to larger and rarer events

Roman will determine if IR flares follow a single power-law to 99.7% confidence vs. stellar mass and age, confirming whether JWST rates are representative or not



How do we estimate flare yields in the GBTDS high cadence seasons?



Populate footprint with 25M sources above the F146W detection limit for high cadence data using Dal Tio+ 2022 stellar population synthesis model

Build 2D grid of TESS flare frequency distributions (FFDs) as functions of stellar mass/age[1], convert into F146W using 9000K flare blackbody

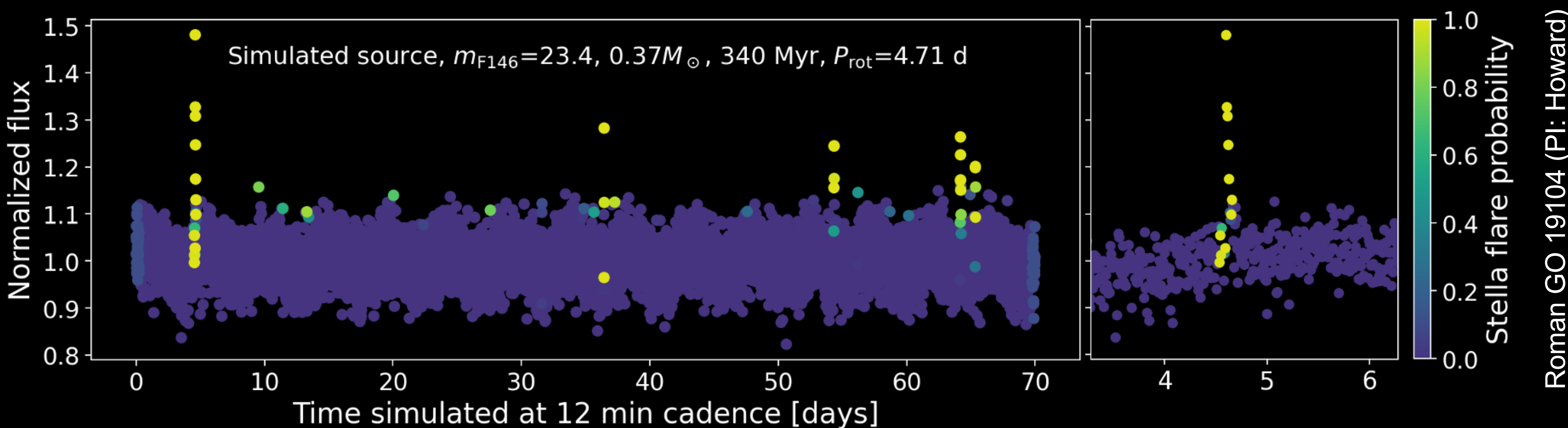
Interpolate FFD parameters of each source on mass/age grid and infer rate of 3σ detections given source mag[2]; sum over sources and seasons

(1) Flare rate grid samples 7x7 mass/age, 49 grid points, only 4 shown

(2) Based on yield code in Howard+ 2025, AJ 169, 27

How are we going to find and validate all these flares? Convolutional classifiers!

We simulate Roman light curves for 10^4 randomly sampled sources, performing flare injection and recovery with the `stella` (Feinstein+ 2020) convolutional neural network

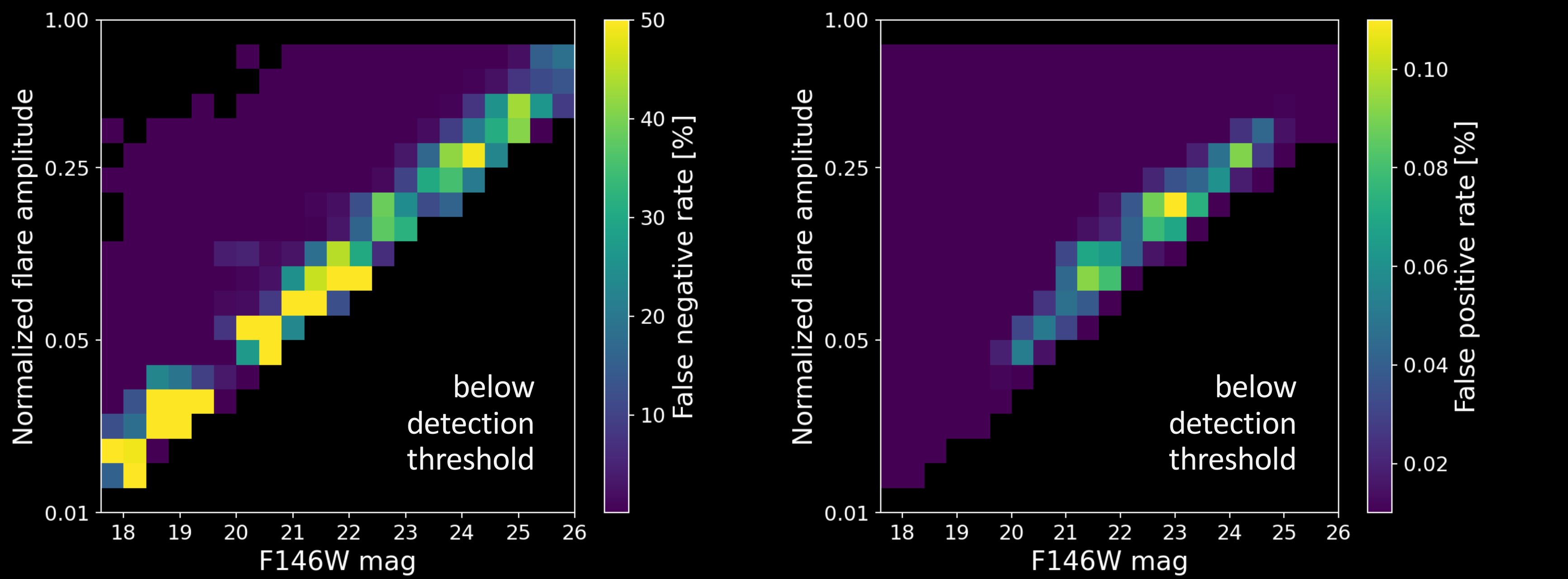


We used model weights pre-trained on TESS flares, the original `stella` use case. We will retrain on Roman data to account for different light curve profiles/systematics

How are we going to find and validate all these flares? Convolutional classifiers!

We report true-positive, false-negative, and false-positive rates of 87%, 13% and 0.5% in the Roman data, respectively, even given the use of pre-trained TESS models.

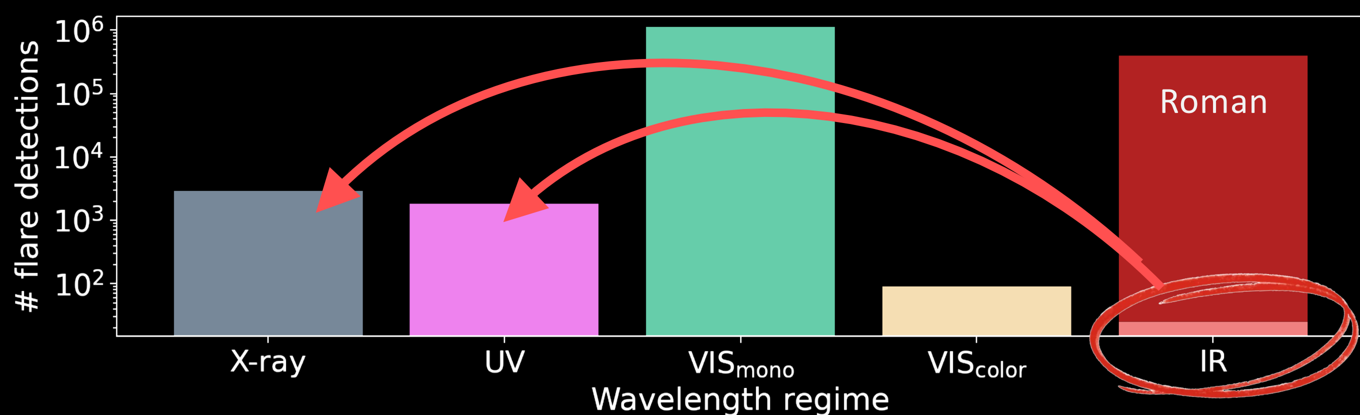
We find accuracy depends most strongly on flare size and F146W magnitude, but also find false positives increase for young sources with strong rotational variability



Roman GO 19104 (PI: Howard)

Connecting IR and shorter-wavelength flares to maximize Roman's scientific impact

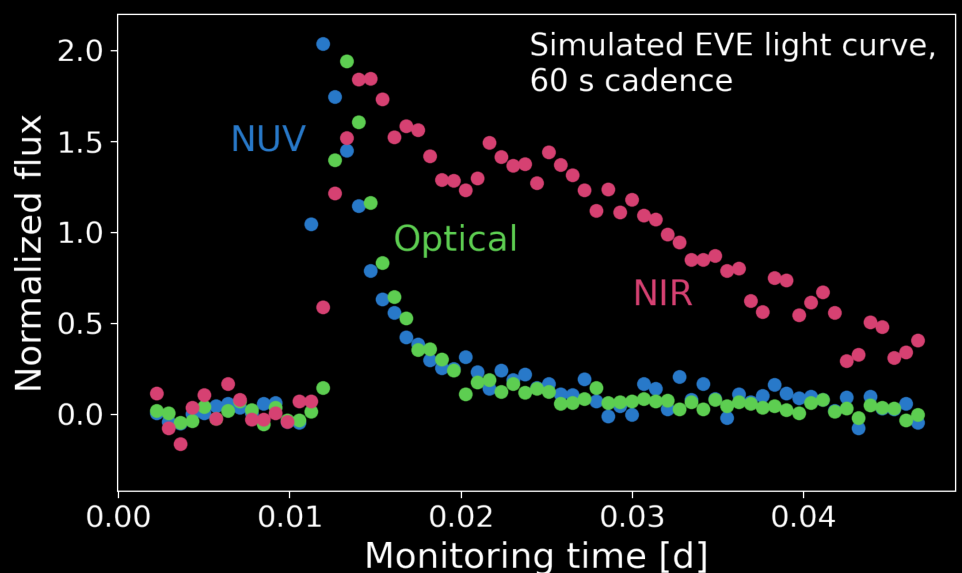
Simultaneous observations are needed to understand how IR flares connect to exoplanet atmospheric escape (X-ray, EUV) and photochemistry (FUV, NUV)



Where will we get a large sample of simultaneous flare observations?

The Early eVolution Explorer (EVE), an astrophysics Small Explorer concept

EVE (PI: MacGregor, JHU) will investigate the early co-evolution of stars and planets with long-term, rapid photometry of 20,000 young stars obtained simultaneously at NUV, visible, and NIR wavelengths



Simultaneous detections of 1300 large flares will identify emission mechanisms and impacts for exoplanet atmosphere observations from JWST to Habitable Worlds

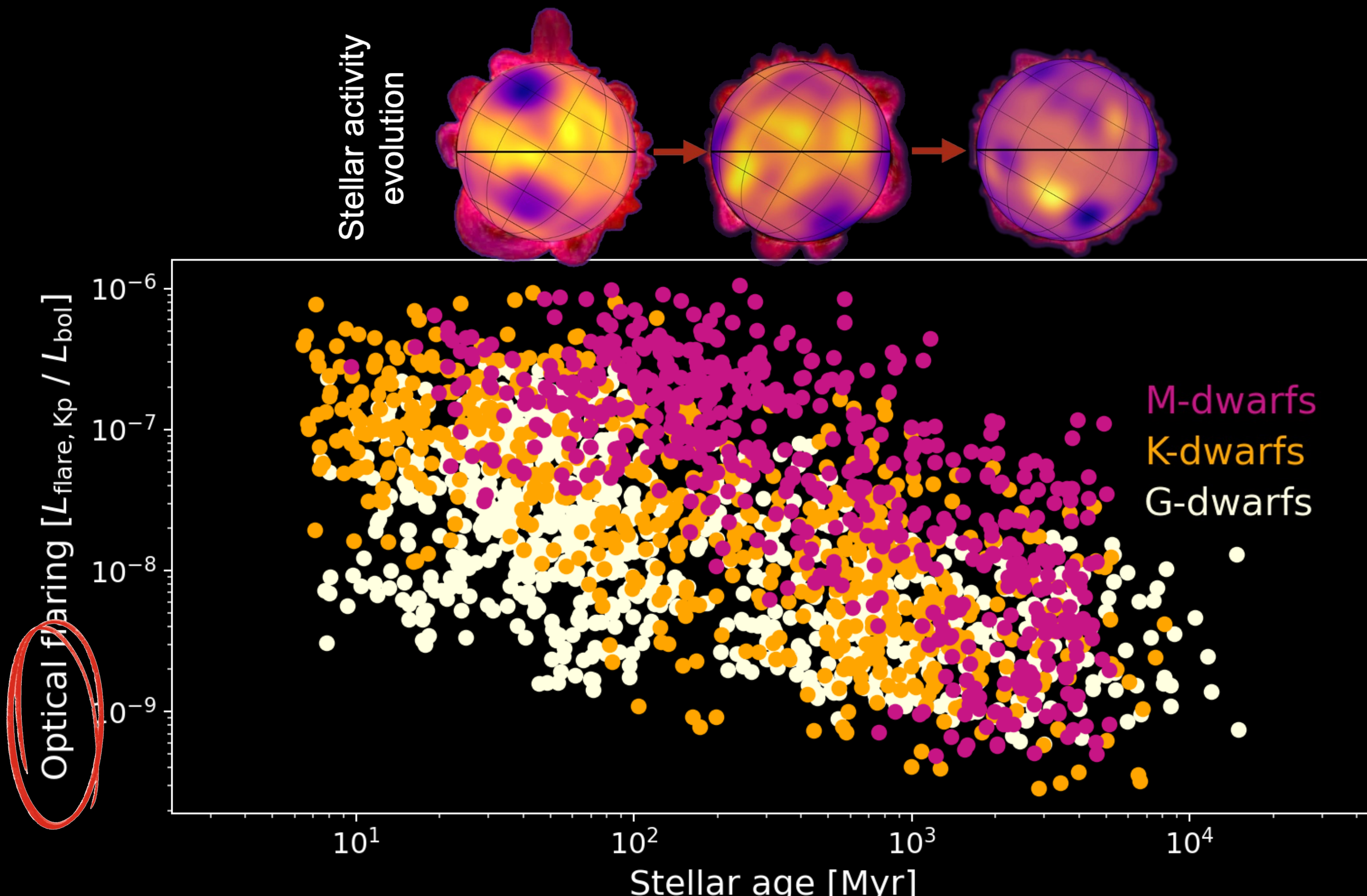
EVE publications: Howard+ 2025, AJ 169, 27; Zhou+ 2026, AJ 172, 62

Key takeaways

- Roman's GBTDS will close the gap in our understanding of infrared flare populations relative to shorter-wavelength regimes
- JWST and Roman provide complementary perspectives on infrared flare rates, with sensitivity to the frequent smaller and rare larger flares, respectively
- Our feasibility study of a neural network flare finder shows the low error rates required to classify 400k flares from 25M sources in simulated GBTDS data
- EVE is a multiwavelength successor to TESS and Roman that will connect infrared flare emission to emission at shorter wavelengths

Backup Slides

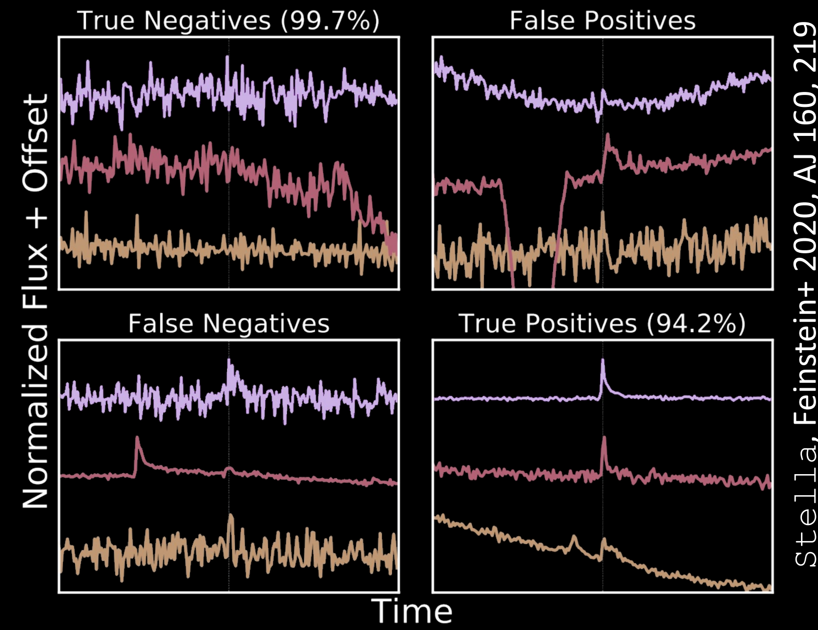
The extended pre-main sequence of lower-mass stars is reflected in their flare rates

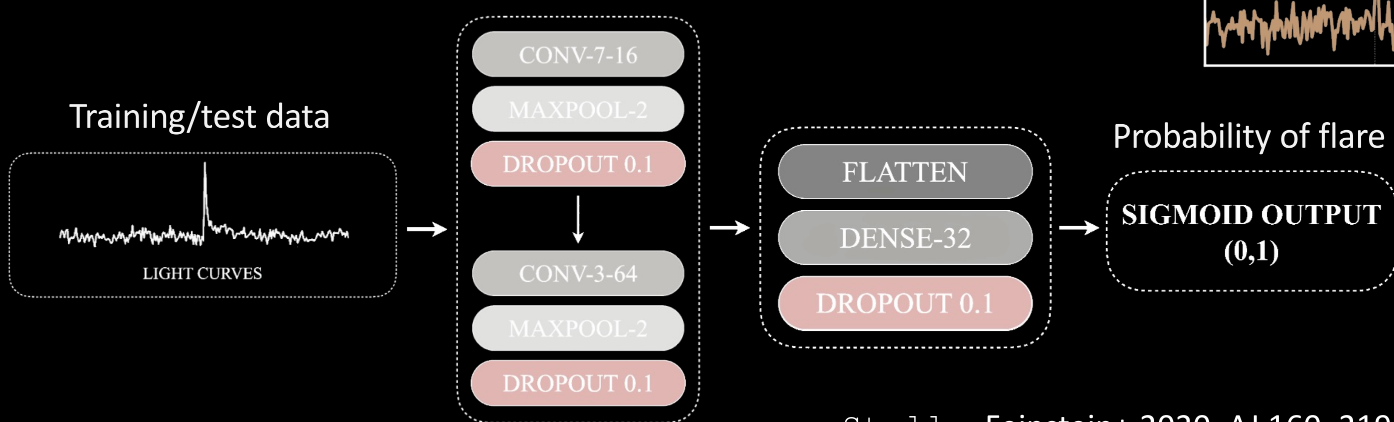


Adapted from Yang & Liu 2019, ApJS 241 29

Stella's convolutional neural network architecture and validation information

`stella` shows high accuracy (98%) & recall (94%) across a wide range of flare sizes and light curve shapes, and successful identification of 936.8k candidates in TESS light curves of 145.1k stars



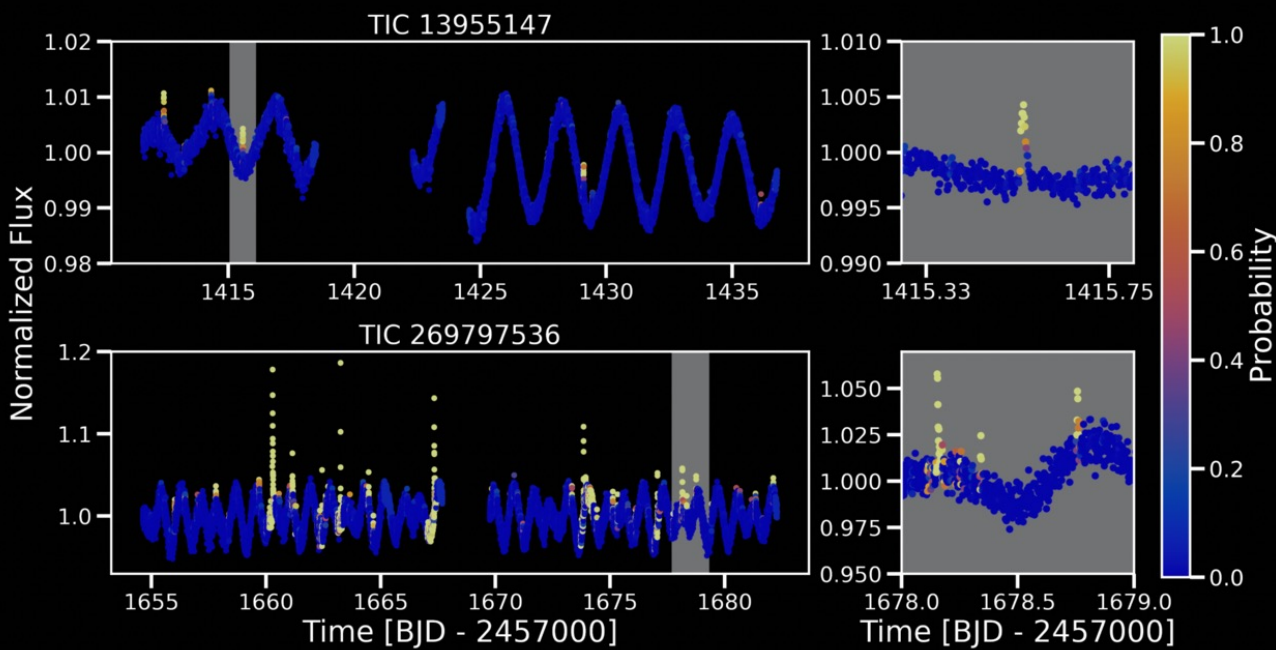


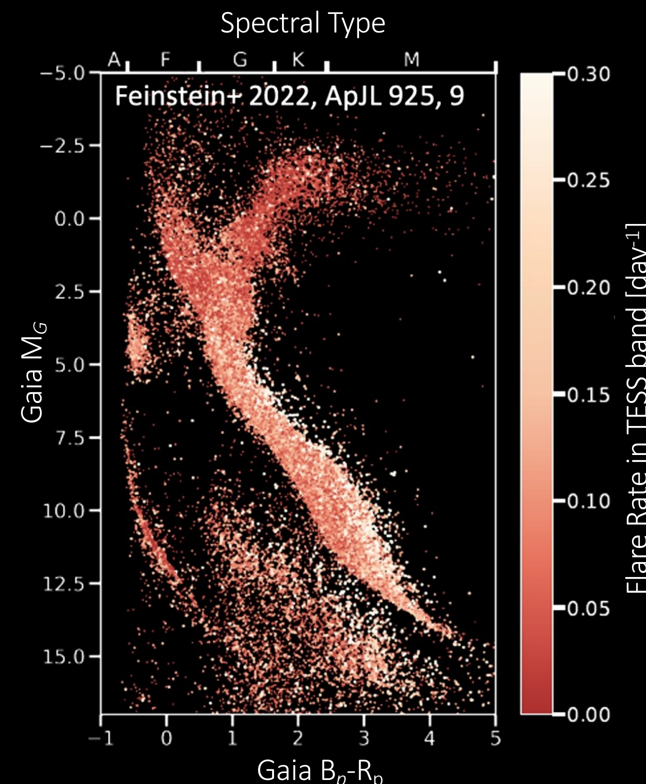
`Stella`, Feinstein+ 2020, AJ 160, 219

How will we find all those flares?

`Stella` is widely used in the flare community; Open source, so architecture serves as a template in developing classifiers for flares in other datasets

`Stella`, Feinstein+ 2020, AJ 160, 219





The Early eVolution Explorer (EVE), a JPL proposal for an astrophysics Small Explorer

EVE (PI: MacGregor, JHU) will investigate the earliest stages in the shared evolutionary pathways of stars and planets, with three goals*

(1) Detect dozens of planets younger than 30 Myr to assess their water inventory

(2) Determine the effects of superflares on atmospheric photochemistry

(3) Discover how accretion impacts angular momentum transport in young disks

EVE is a multi-wavelength successor to TESS:

EVE
EARLY eVOLUTION EXPLORER

- ✓ Simultaneous NUV, optical and IR photometry of 20,000 young stars
- ✓ Observes nearby clusters at 60 s cadence and with 20-50 d stares
- ✓ Three co-mounted telescopes of 10—20 cm and a 25 deg^2 field

*and ancillary science, e.g. asteroseismology of low mass stars