Characterizing Transiting Planet Host Stars

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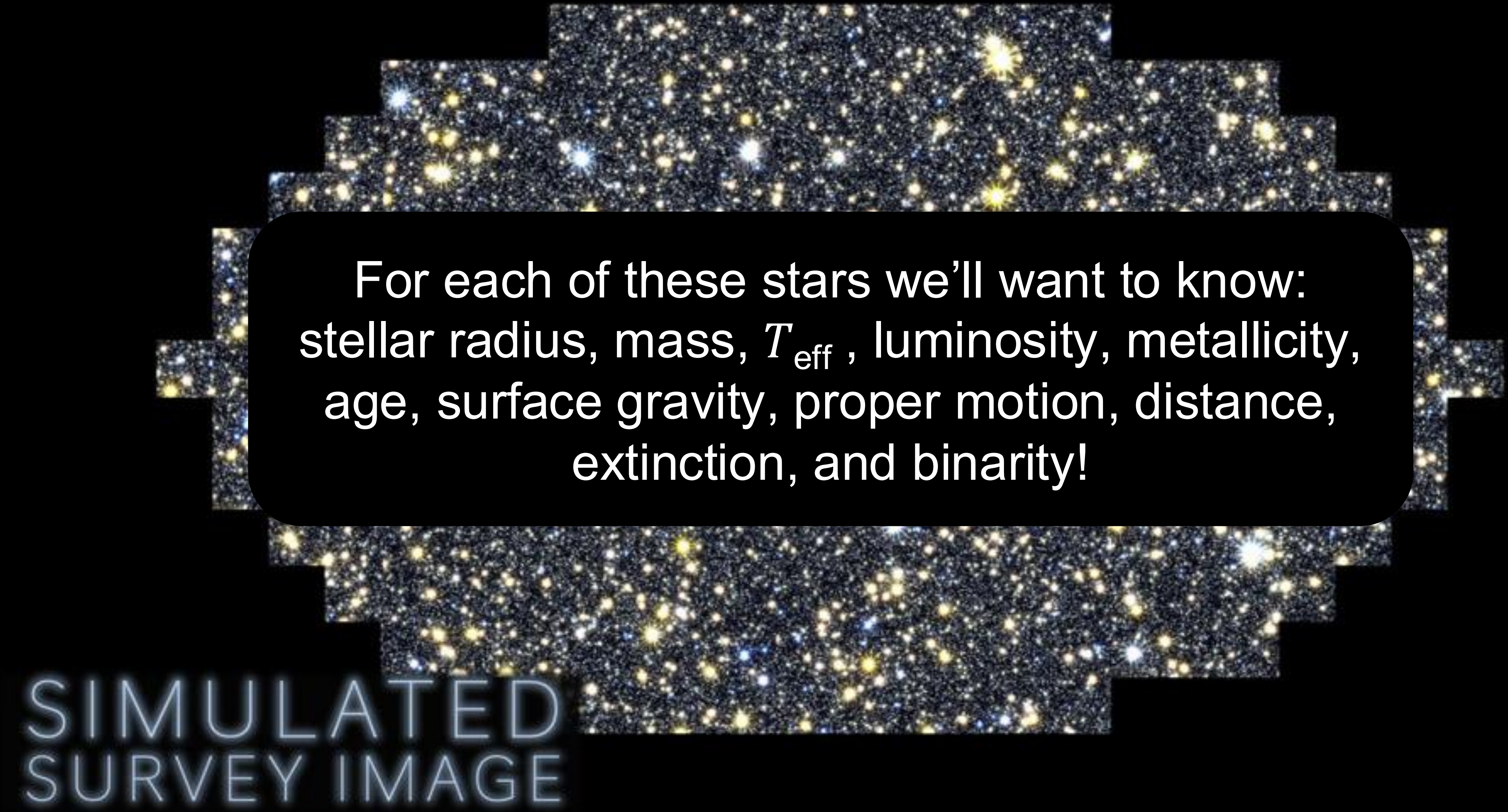
Could discover **100,000 new transiting exoplanets** (Wilson et al. 2023)

Roman Galactic Bulge Time Domain Survey will observe ~100 million stars!



For each of these stars we'll want to know:
stellar radius, mass, T_{eff} , luminosity, metallicity, age, surface gravity, proper motion, distance, extinction, and binarity!

Credit: NASA's Goddard Space Flight Center/Matthew Penny

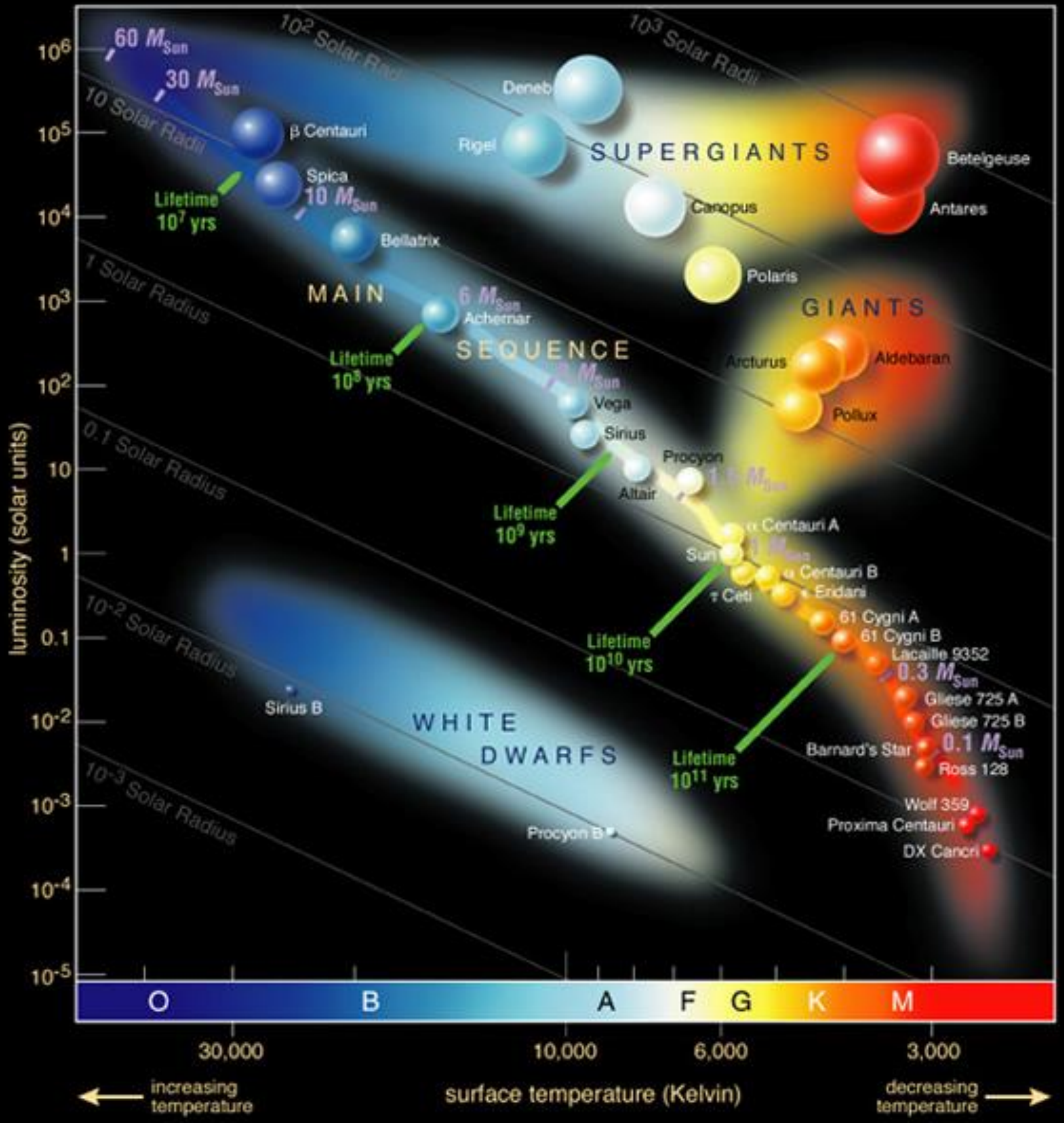


Image Credit: ESO

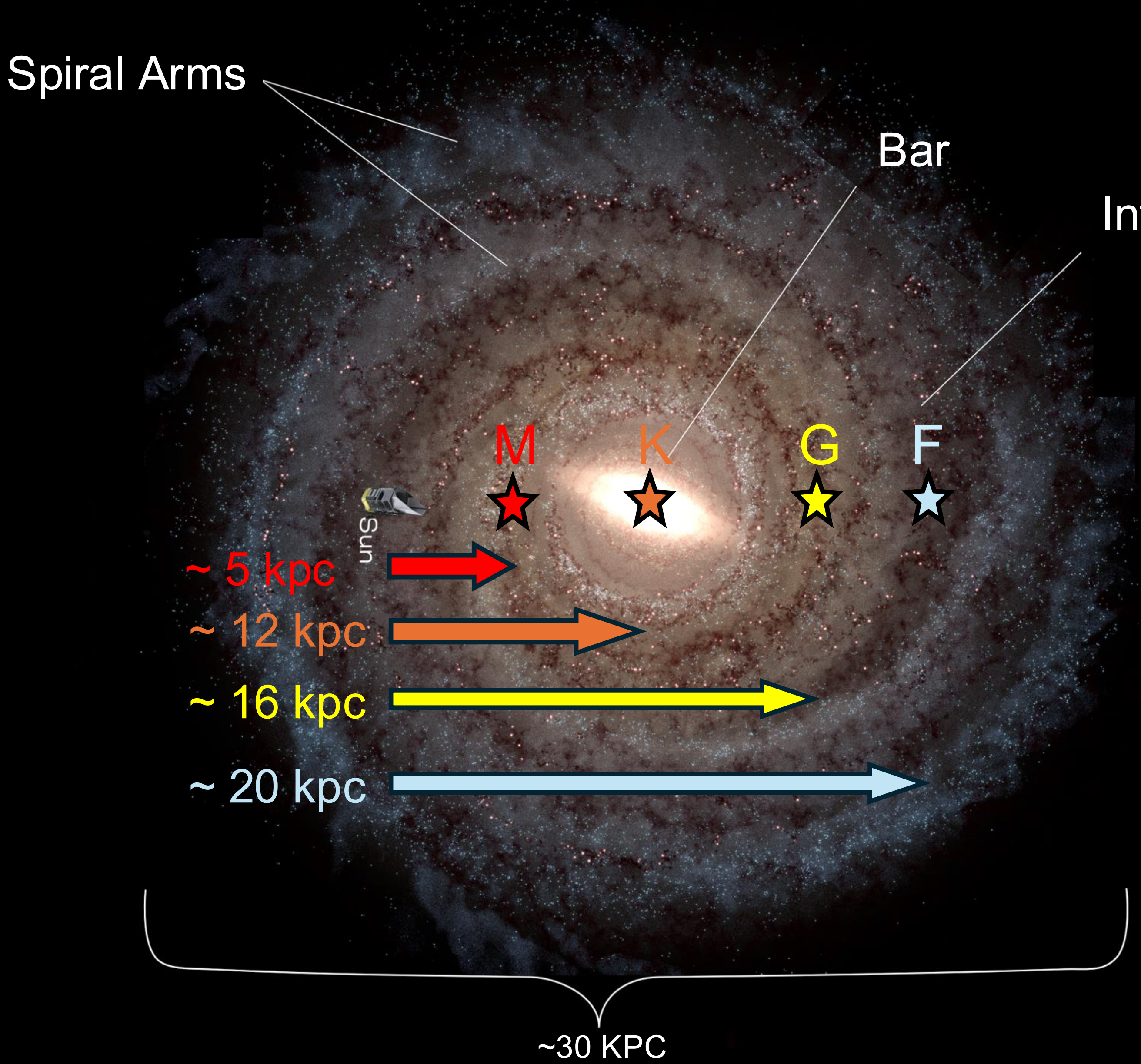
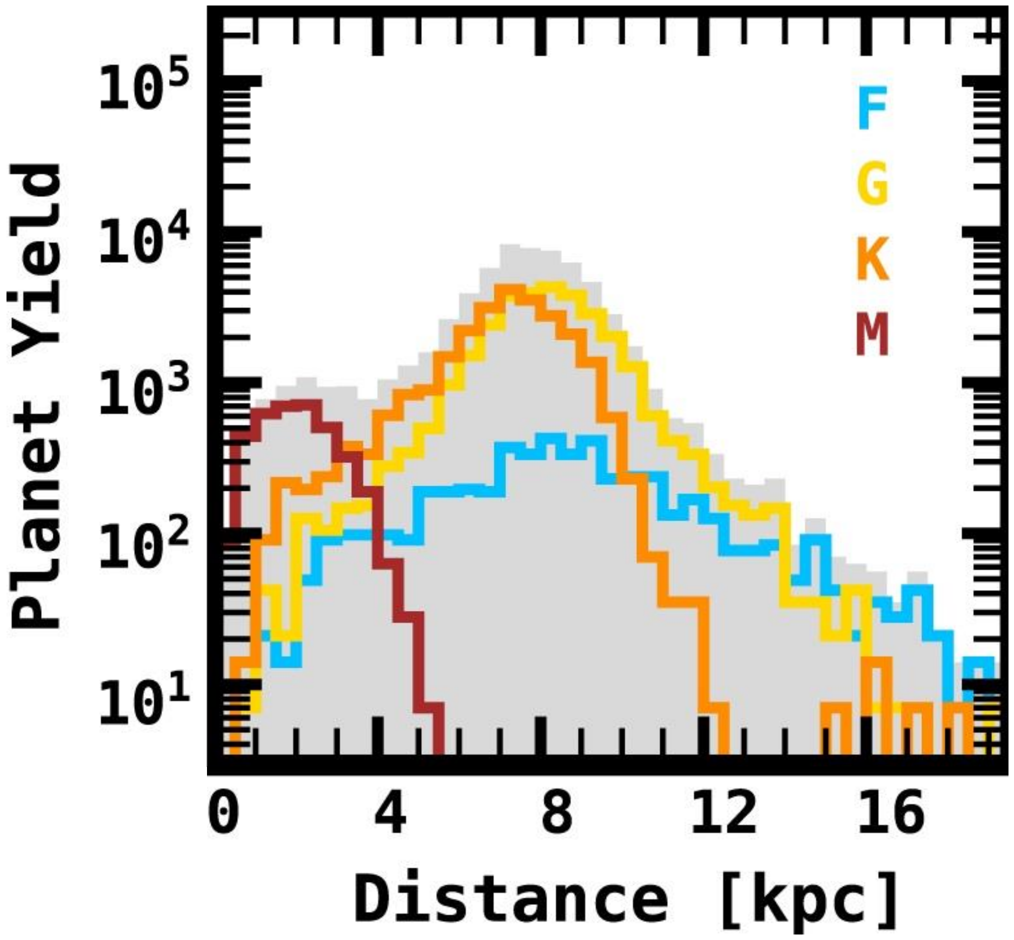
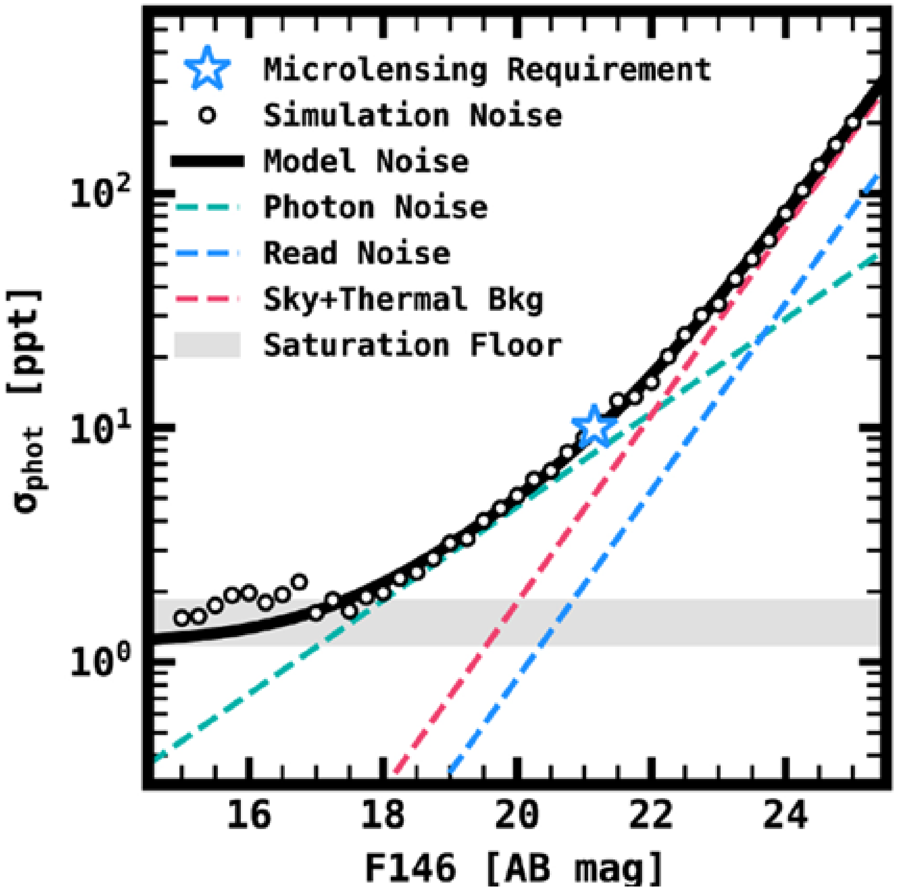


Illustration Credit: NASA's Goddard Space Flight Center

Adapted from Wilson et al. 2023

We will be able to detect transits down to ~23 mag





Wilson et al. 2023

How do we know how big stars are?

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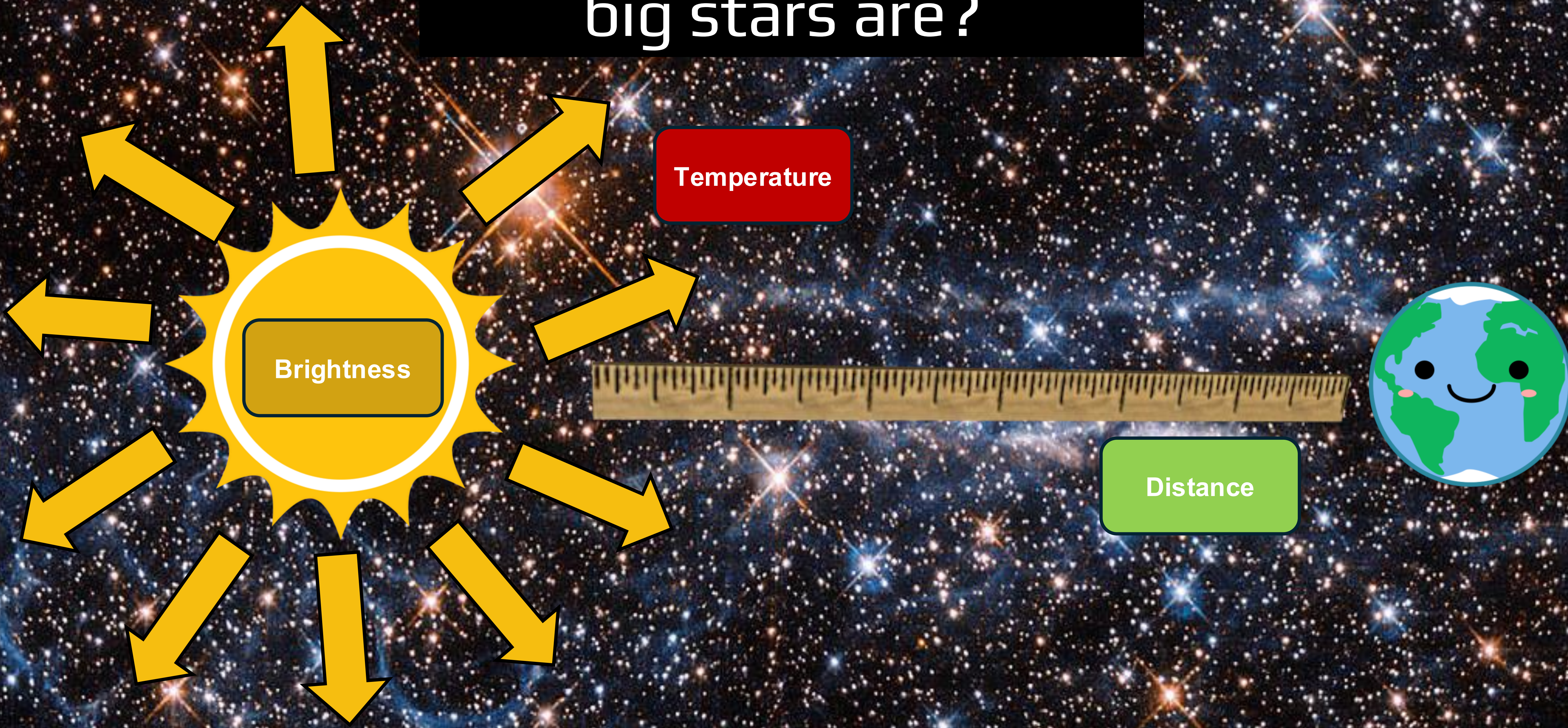


Spectral Energy Distribution Fitting

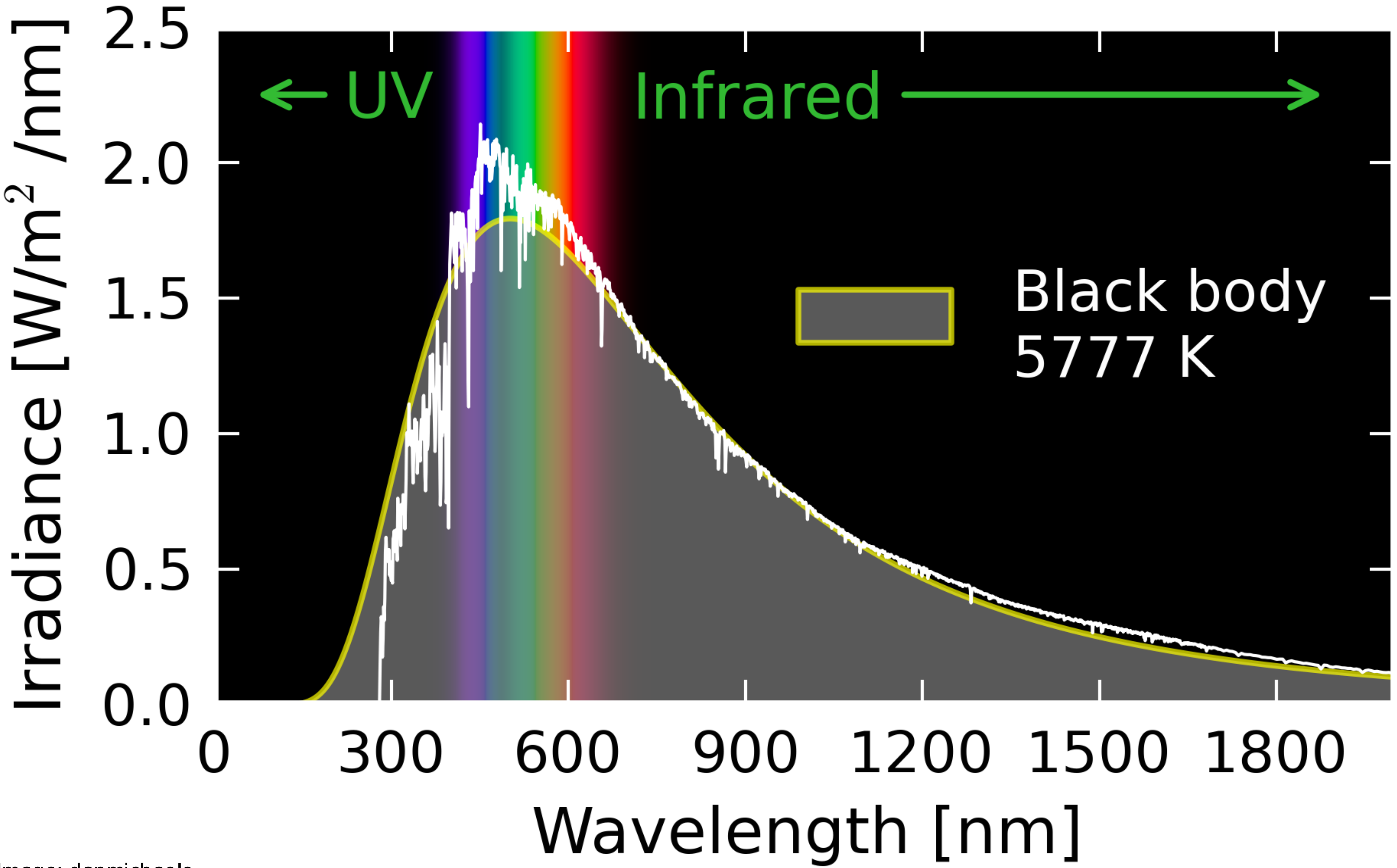
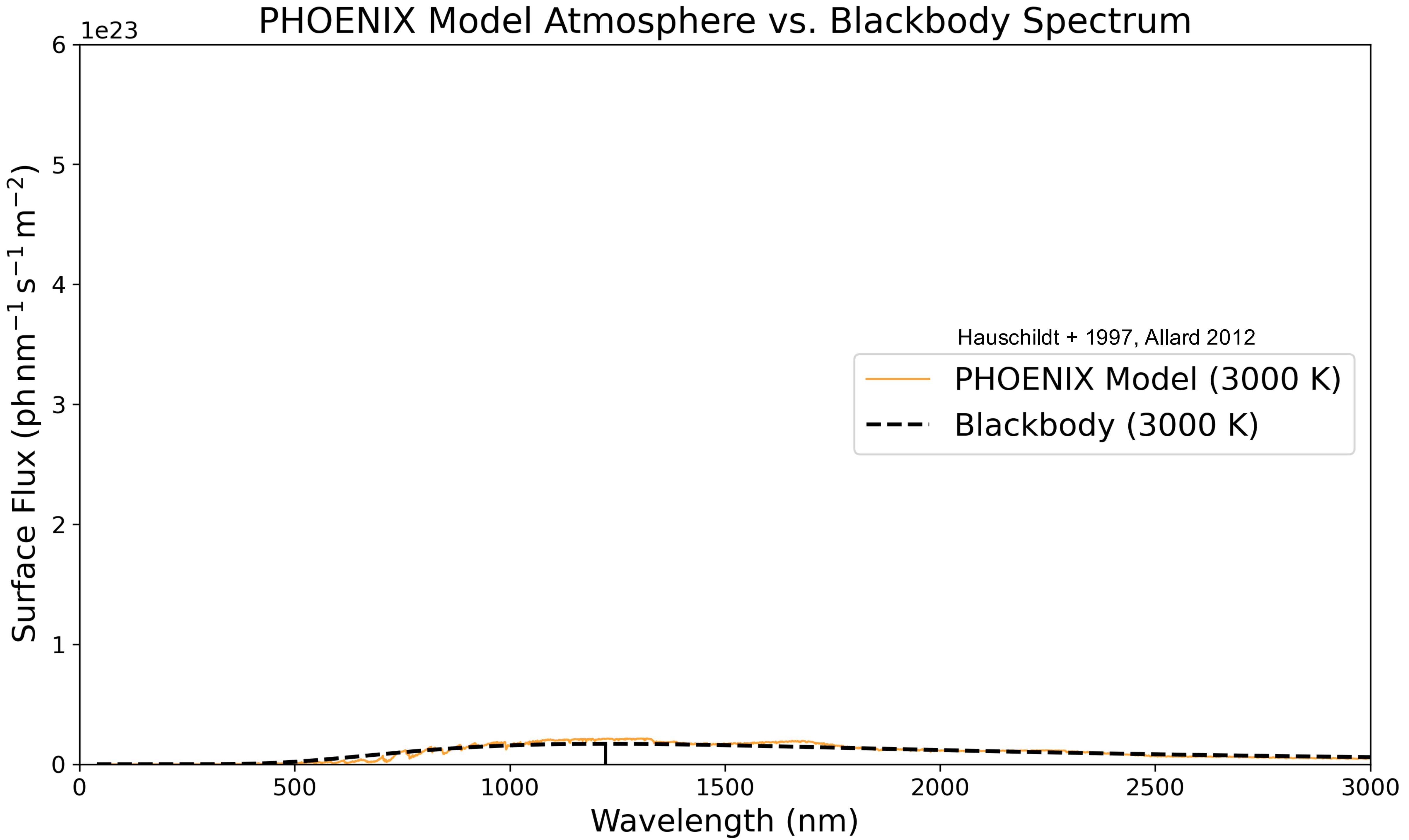
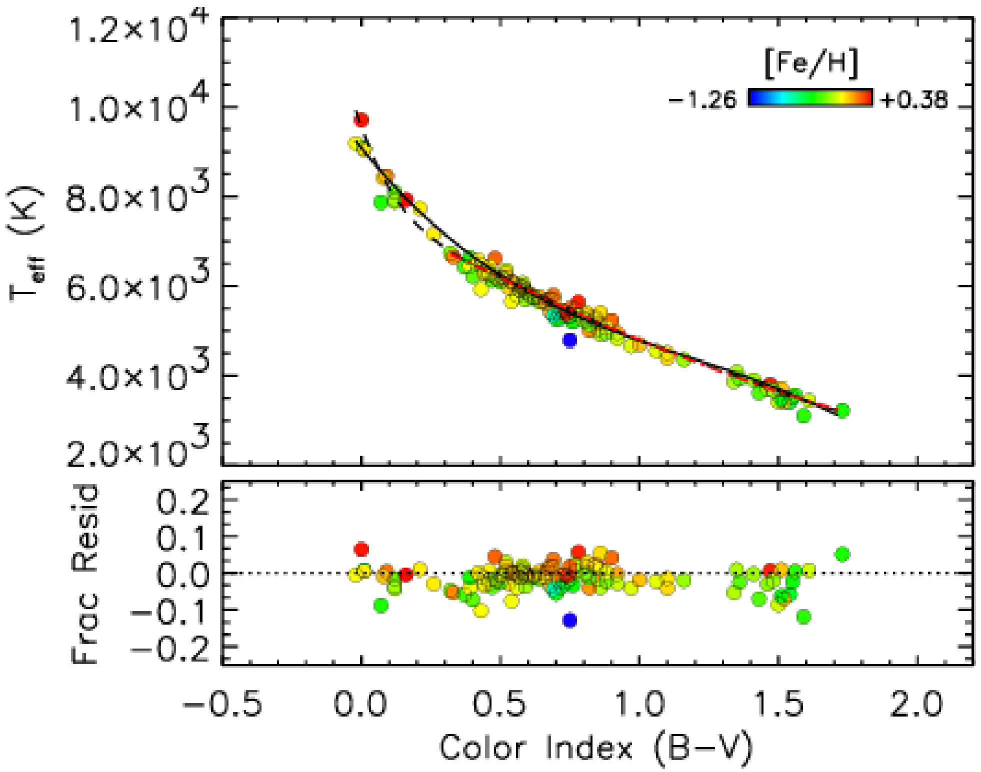


Image: danmichaelo

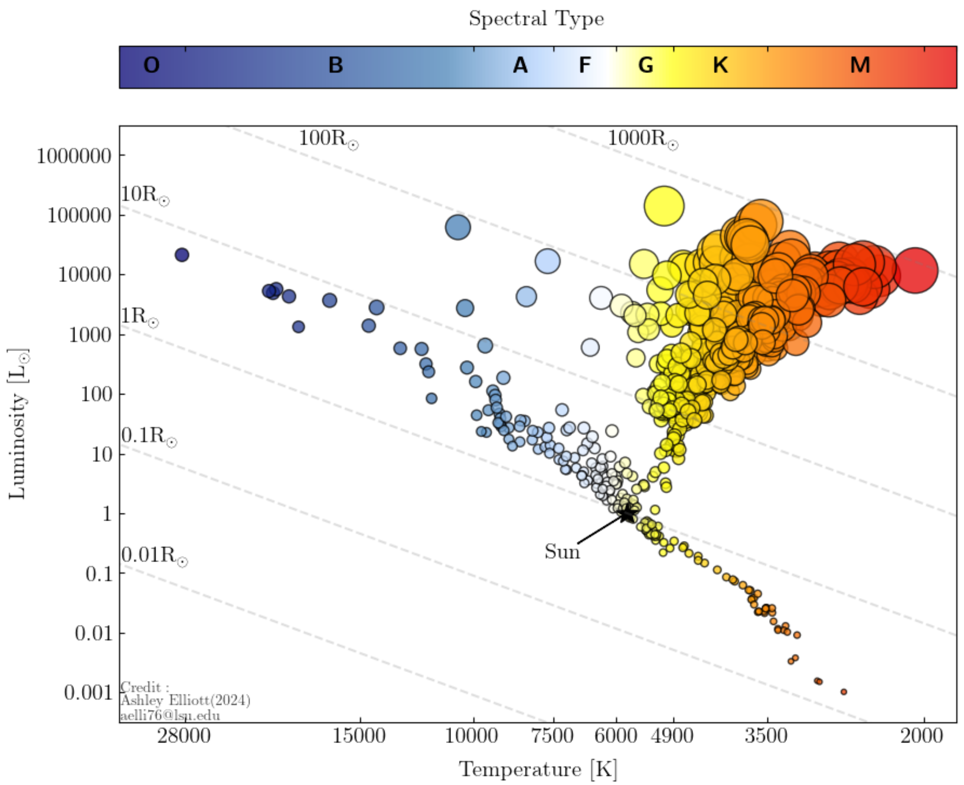


PHOENIX Model Atmosphere vs. Blackbody Spectrum
1e23
Surface Flux (ph nm^{-1} s^{-1} m^{-2})
Wavelength (nm)
0
500
1000
1500
2000
2500
3000
1
2
3
4
5
6
Hauschildt + 1997, Allard 2012
PHOENIX Model (3000 K)
Blackbody (3000 K)

Color Temperature Relationships

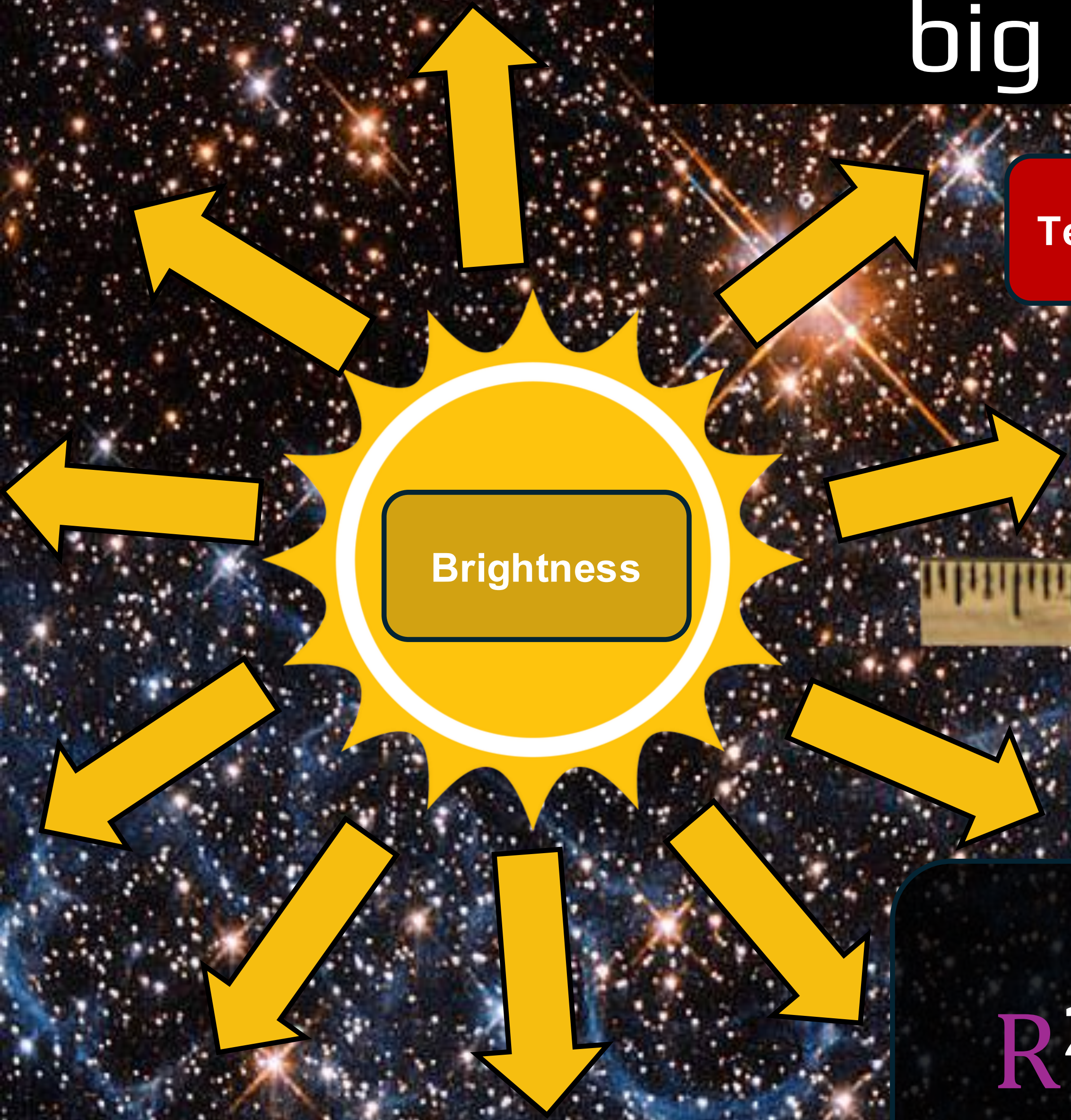


Boyajian et al. 2013



Ashley Elloitt

How do we know how big stars are?



Temperature

$$L = B4\pi d^2$$

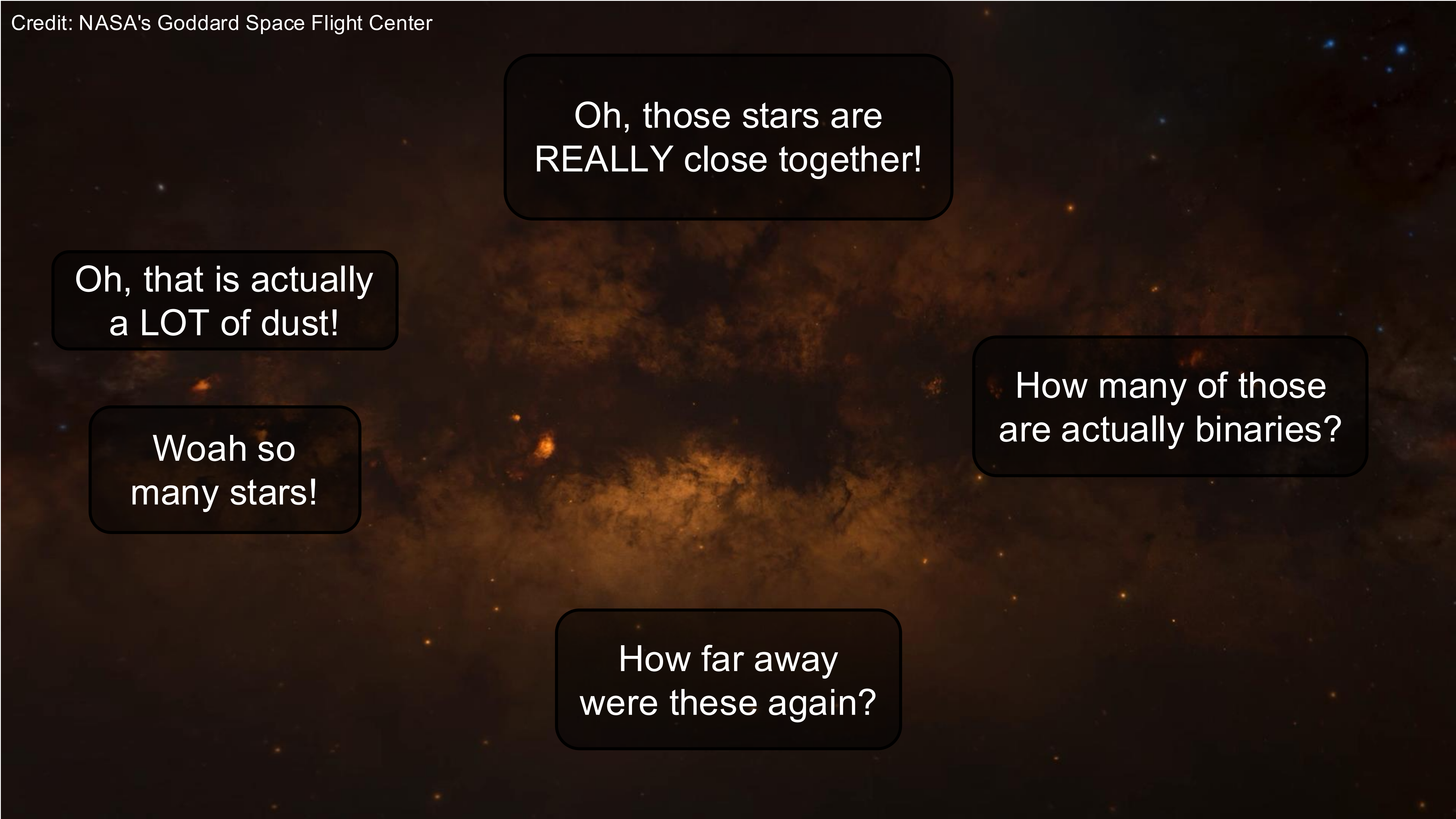
Distance

$$R^2 = \frac{L}{4\pi\sigma T^4}$$

Hmmmmmm……

😕

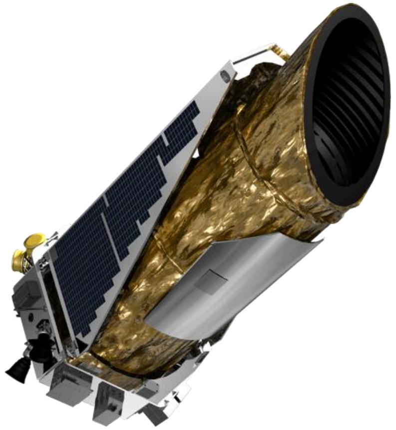
We may have some problems



Credit: NASA's Goddard Space Flight Center

But! We’ve been here before!

So what did we do then?



Kepler and Roman

Similarities

- *Limited distances initially*
- Faint Sources
- Some precursor imaging
- Great for discovering transiting planets
- Largely statistical validation of false positives

Differences

- Kepler still had a lot of ground based follow up
- Roman will have dramatically more extinction and more complicated extinction profiles
- Roman will probe a wider range of galactic positions
- Roman will have dramatically more crowding
- Roman will produce its own parallax and distance estimates

The Creation of the Kepler Input Catalog

Primary Goal – to distinguish between **cool giant** and **dwarf stars** with good reliability

(Brown et al. 2011)

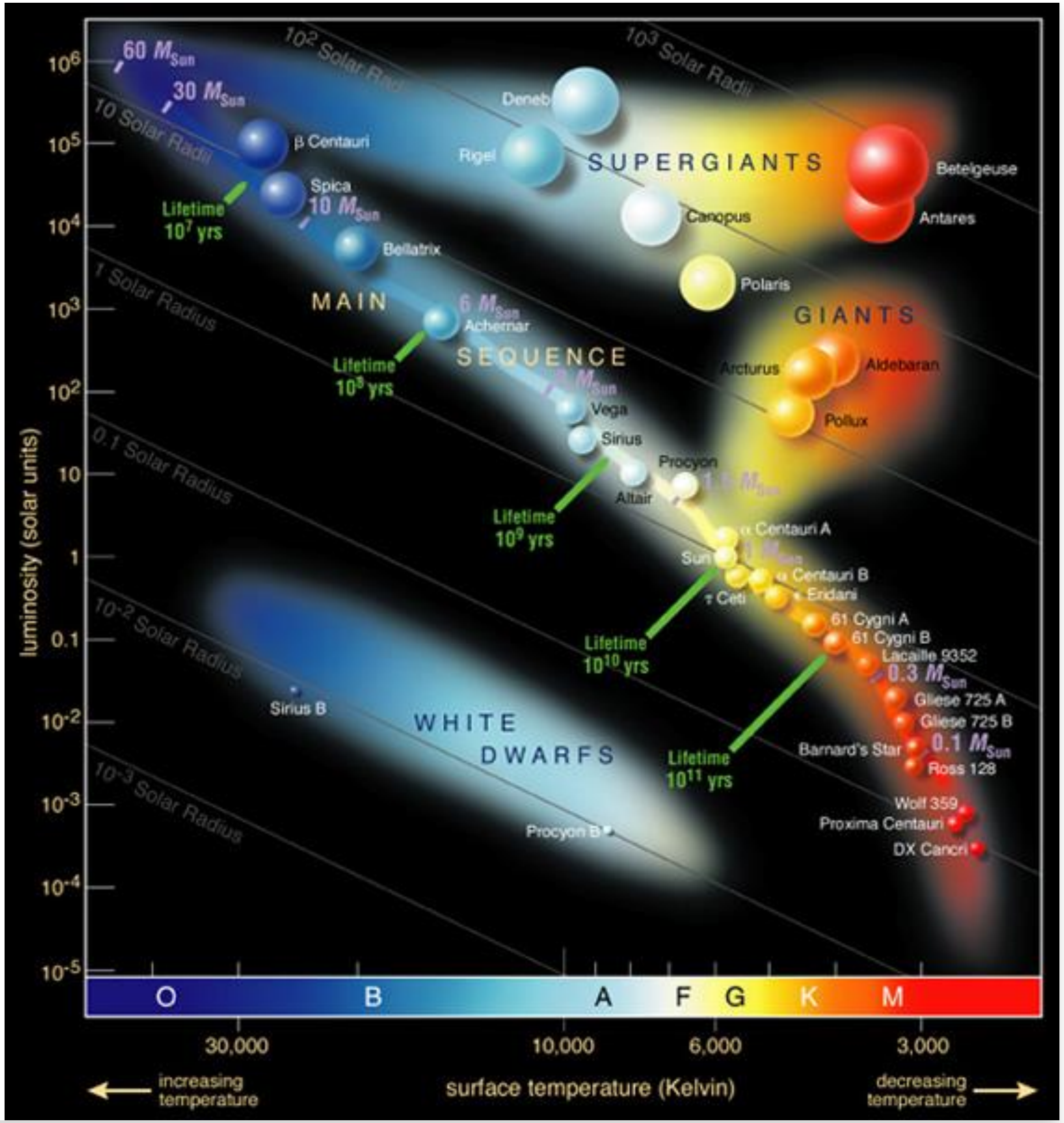


Image Credit: ESO

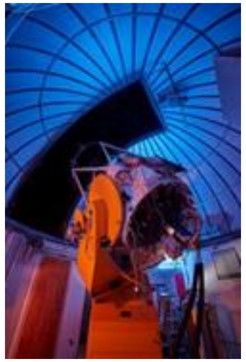
KIC Pipeline – Brown et al. 2011

- **First**, ingested the raw **photometric catalogs**

Skrutskie et al. 2006

USNO-B1.0 (Monet et al. 2003)
UCAC2 (Zacharias et al. 2004)

ESA 1997; Perryman et al. 1997
Tycho2 (Høg et al. 2000),

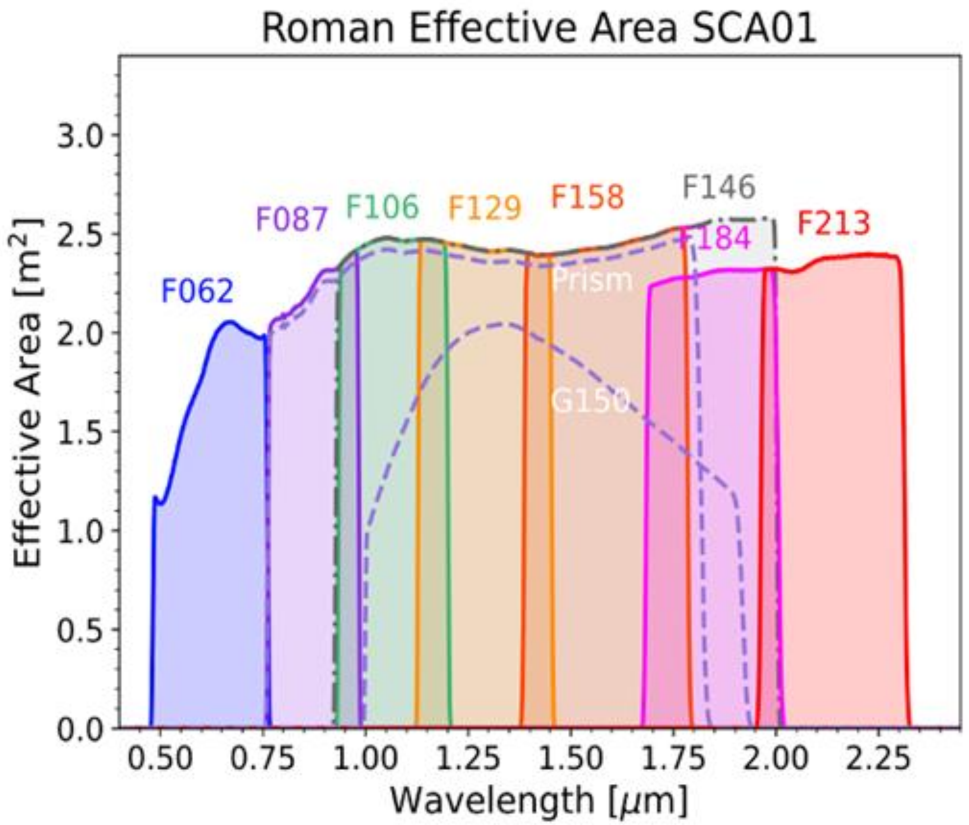


Broad band photometry from the Whipple Observatory 1.2m in the *filters g, r, i, z, and D51*

We can do that!

Roman itself will conduct photometric observations.

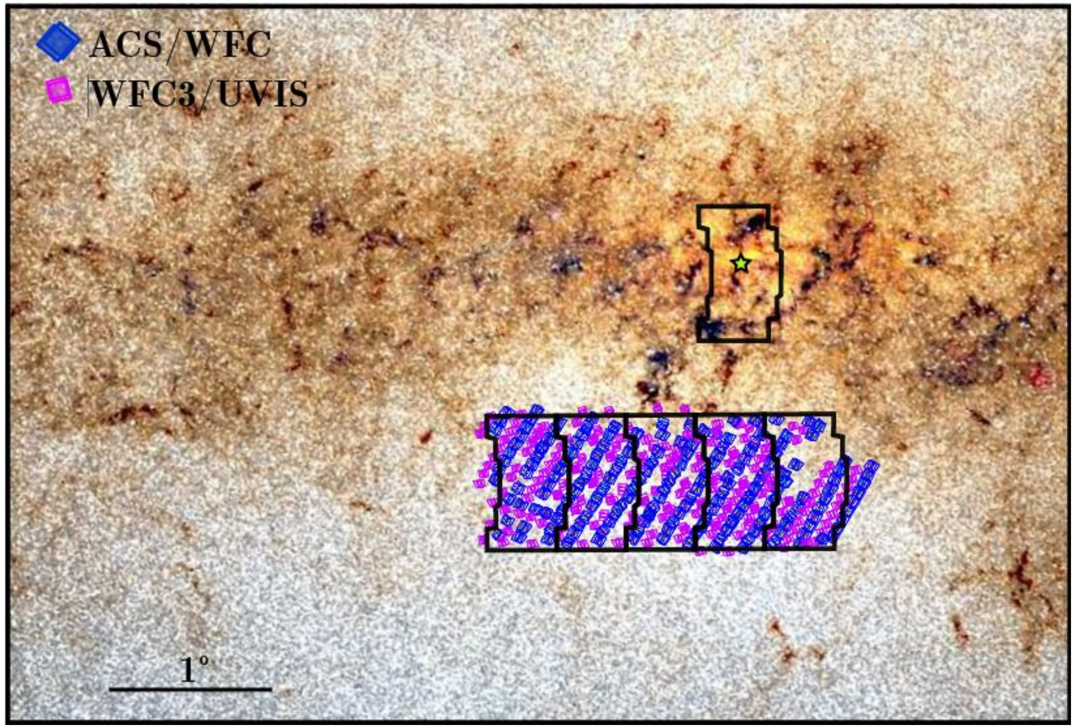
Survey Component	# Seasons	Optical Element	Epochs per Season (~)	Observation Cadence (Within a Season)
High Cadence Seasons	6	F146	8390	12.1 minutes
		F087	282	6 hours
		F213	282	6 hours
		Photometric Snapshot		
		F184	3	~35 days
		F106		
		F129		
		F158		
		F062		
		Spectroscopic Snapshots		
		GRISM	3	~35 days



Credit: roman-docs.stsci.edu

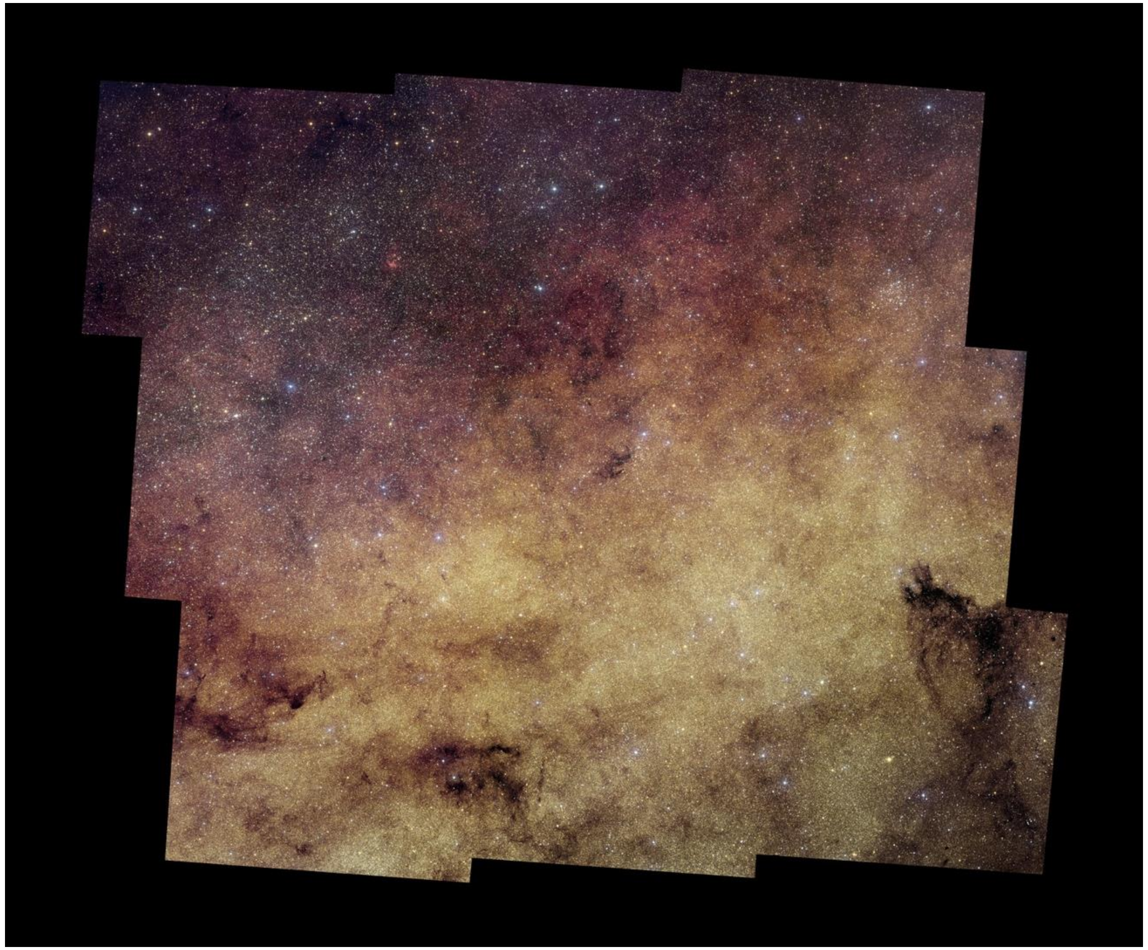
Roman as lots of friends!

- Hubble! Terry et al. 2026 conducted a campaign to cover ~70% of the Galactic bulge time domain survey footprint!



Roman as lots of friends!

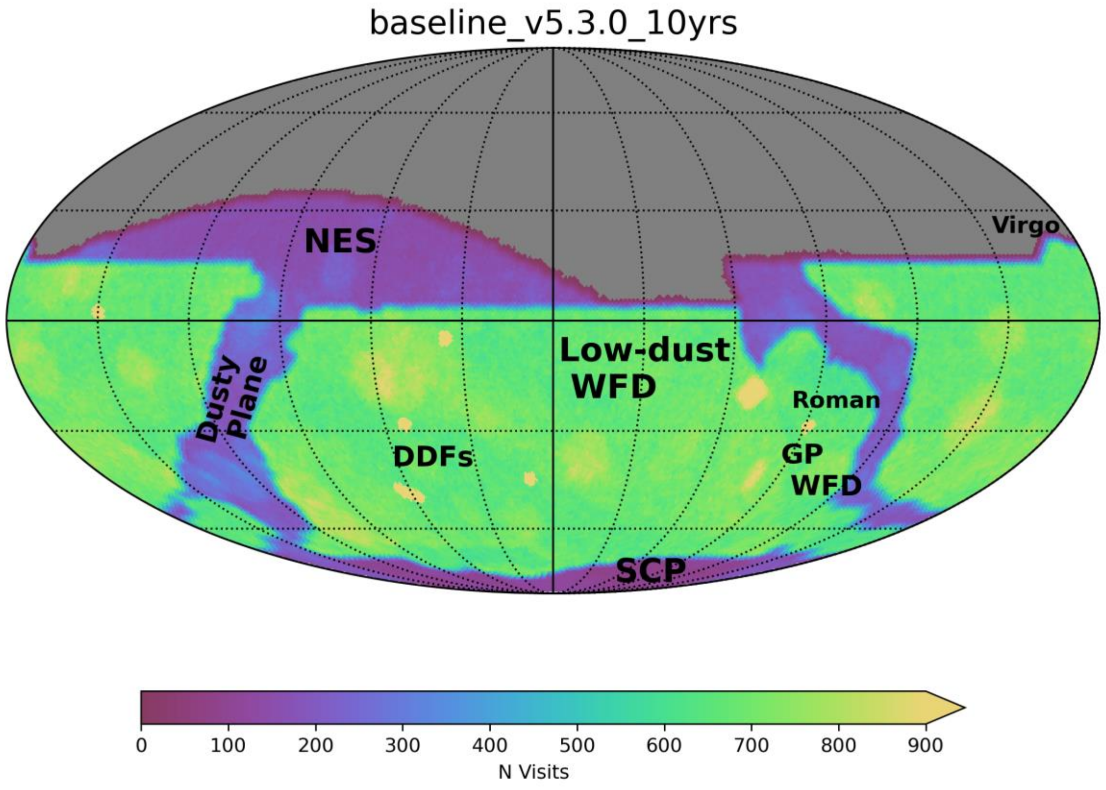
- **Euclid** Galactic Bulge Survey!
- Recently had their first data release with 4.8 deg^2 and 45 million detected sources!
- Beaulieu et al. 2026



Credit: ESA/Euclid/Euclid Consortium/NASA, CFHT, image processing by J.-C. Cuillandre and E. Bertin (CEA Paris-Saclay)

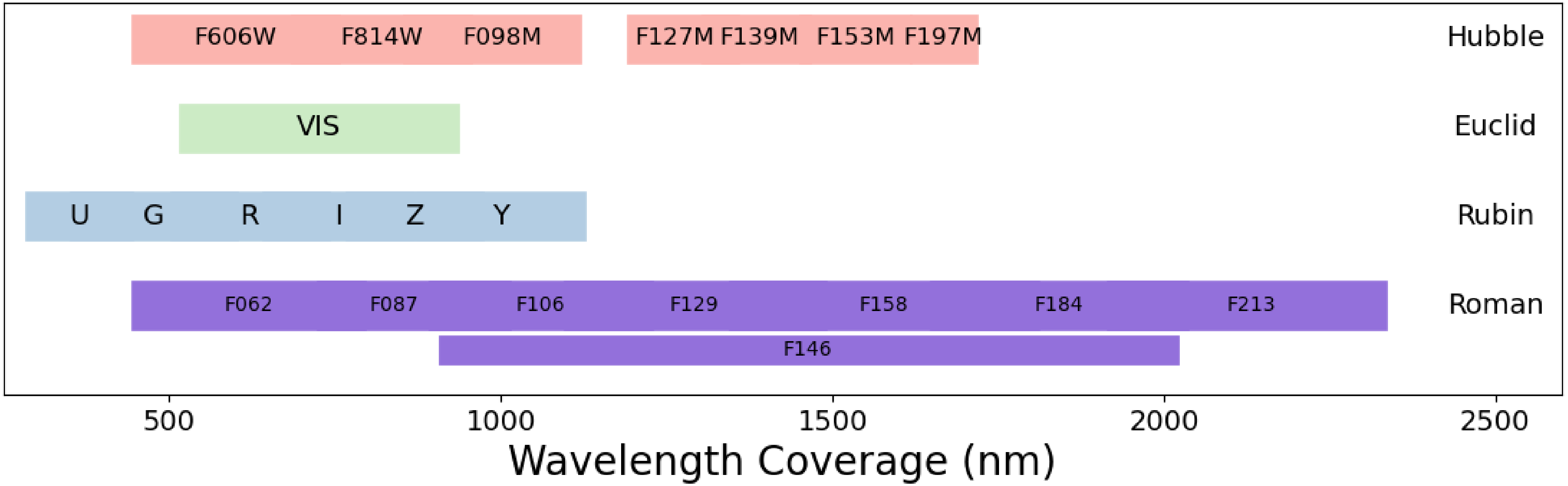
Roman as lots of friends!

- The Vera **Rubin Observatory** will provide numerous observations of the Roman GBTDS fields
- The angular resolution of Roman can be used to de-blend the ground based Rubin photometry.



https://survey-strategy.lsst.io/baseline

Photometry Party!



KIC Pipeline – Brown et al. 2011

- First, ingested the raw photometric catalogs
- **Second**, estimated and corrected the atmospheric extinction suffered by each measurement, and accounted for **interstellar extinction**

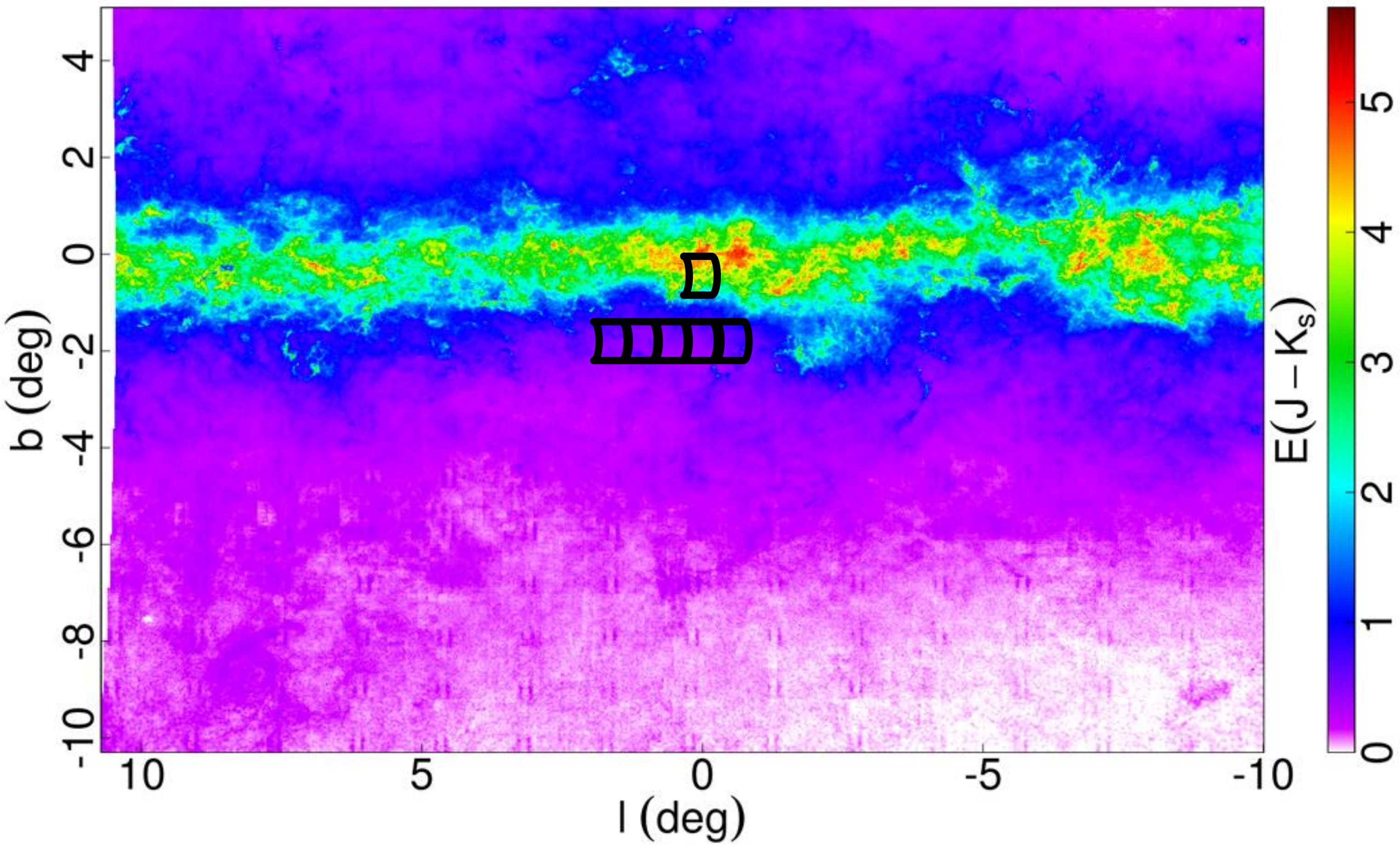
Extinction – Brown et al. 2011

Image: LDN 483, ESO

- Interstellar reddening is significant for most of the stars in the Kepler field
- Assumed that dust is distributed in a smooth disk aligned with the plane of the Milky Way, having an exponential decay of density with height above the plane.
- Model used contains no small scale structure

Resulted in systematic misclassification of many stars, a scattered relation between Teff and color, and other complications.

Current dust maps: Surot et al. 2020



Ongoing Hubble observations will improve resolution of GBTDS field dust maps further (See David Nataf's Talk!)

As Roman parallax measurements improve, we will be able to create dust maps from Roman itself

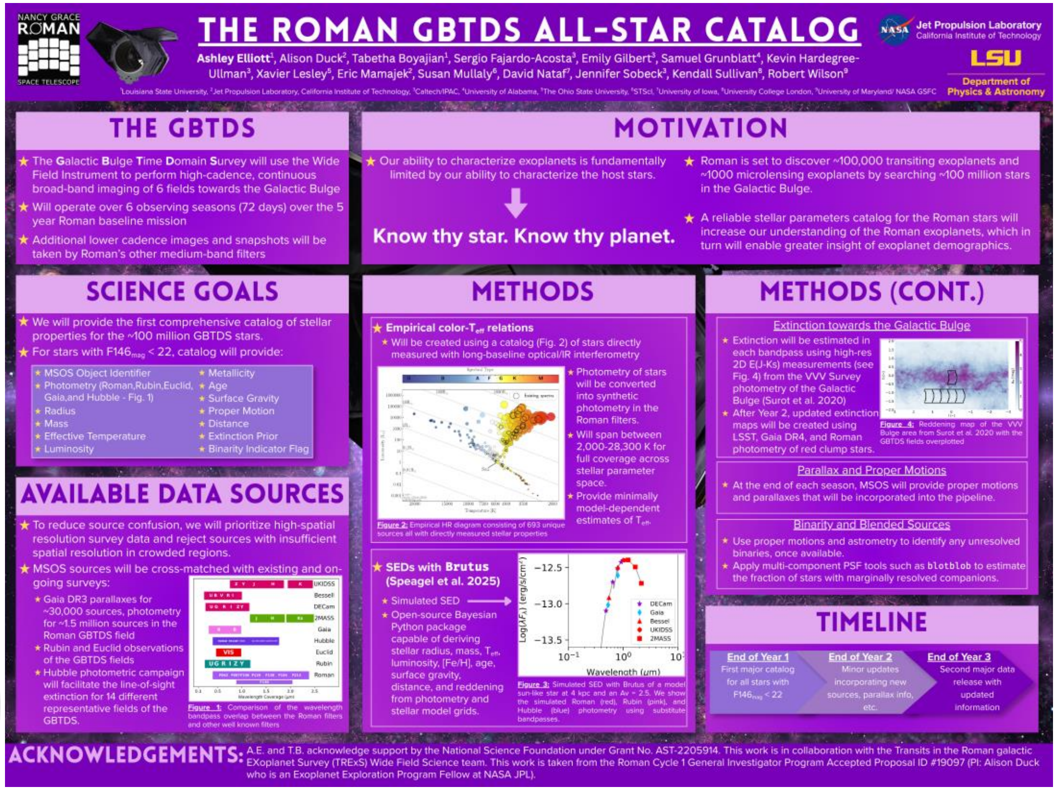
KIC Pipeline – Brown et al. 2011

- First, ingested the raw photometric catalogs
- Second, estimated the atmospheric extinction suffered by each measurement, and corrected the instrumental stellar magnitudes to yield calibrated ones
- **Third**, combined the calibrated magnitudes with other information (e.g. stellar atmosphere models - Castelli & Kurucz 2004) to estimate the physical parameters of each observed star, including **Teff**, **log(g)**, **[Z]**, radius **R**, mass **M**, and interstellar reddening $\mathbf{E_B\!-\!V}$

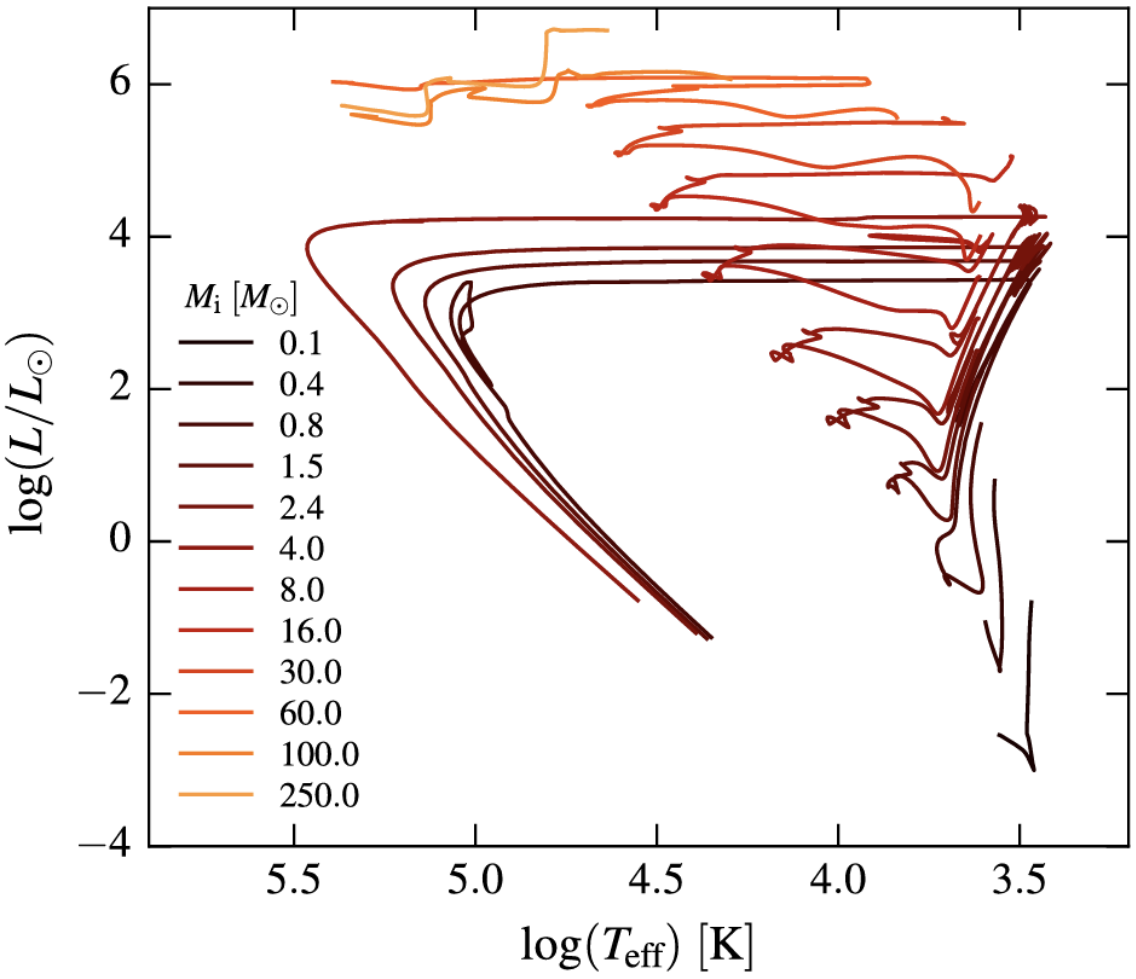
Color-Temperature Relationships

We can use updated empirical color-Teff relationship based on interferometry measurements on our samples of Roman stars!

See Ashely Elliott’s Poster!



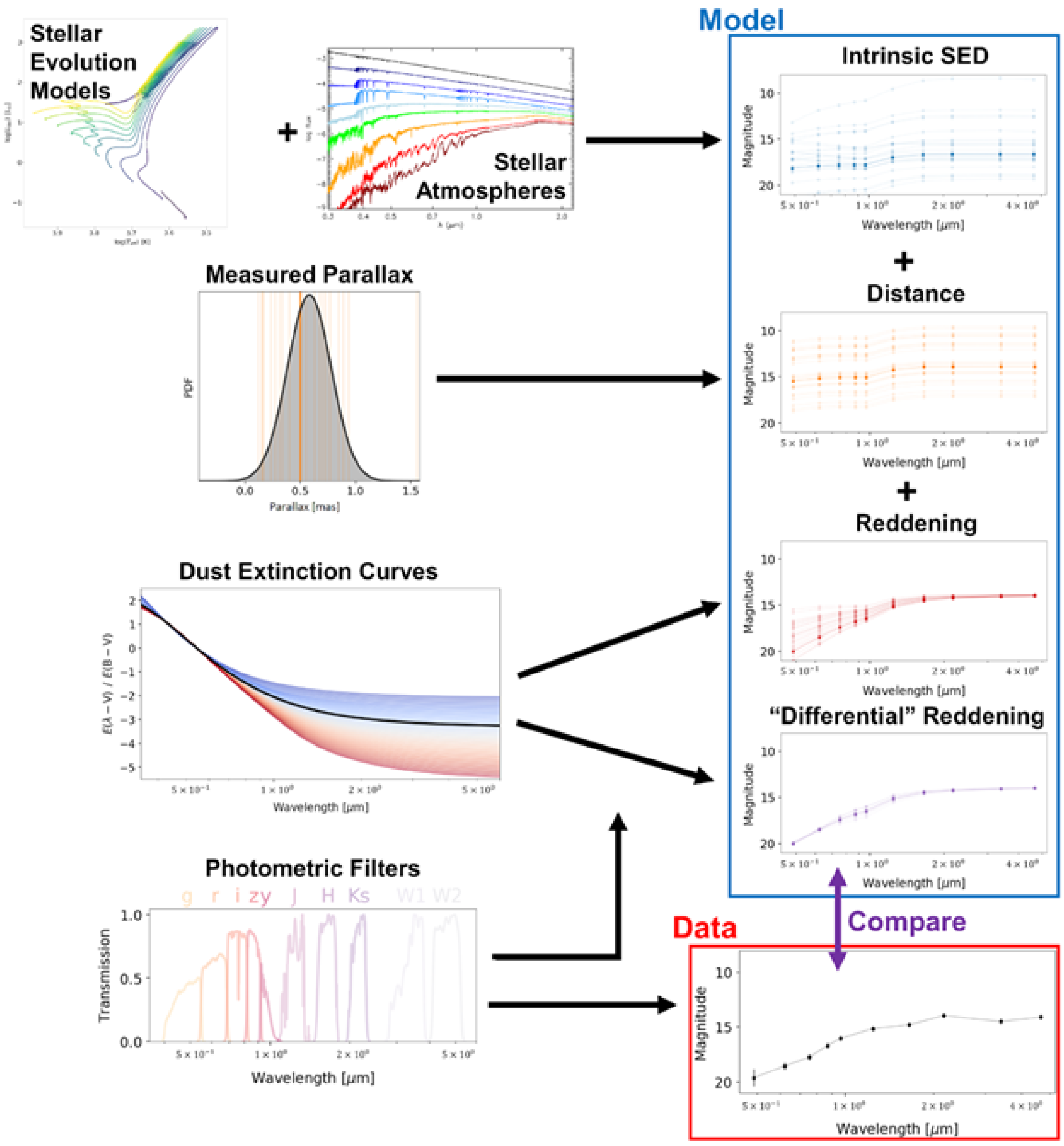
Stellar Evolution Tracks



Choi et al. 2016

- MIST (MESA Isochrones and Stellar Tracks, Choi+2016)
- Uses stellar physics to model the evolution of stars over their lifetimes
- Provides grids of physical combinations of masses, luminosities, surface gravities, metallicities, and ages for many types of stars!

Some tools exist!



- Model of ***BRUTUS*** from Speagel, Zucker et al. 2025
- Being developed for applications in the Galactic Plane and to generally be applicable to Roman data
- Can incorporate photometric observations with stellar evolution and atmosphere models with extinction estimates informed by dustmaps to estimate stellar properties
- Other tools like ***isochrones*** (Morton+2015) and ***isoclassify*** (Huber+2017, Berger+2020, Berger+2023)

Speagle, Zucker, et al. 2025

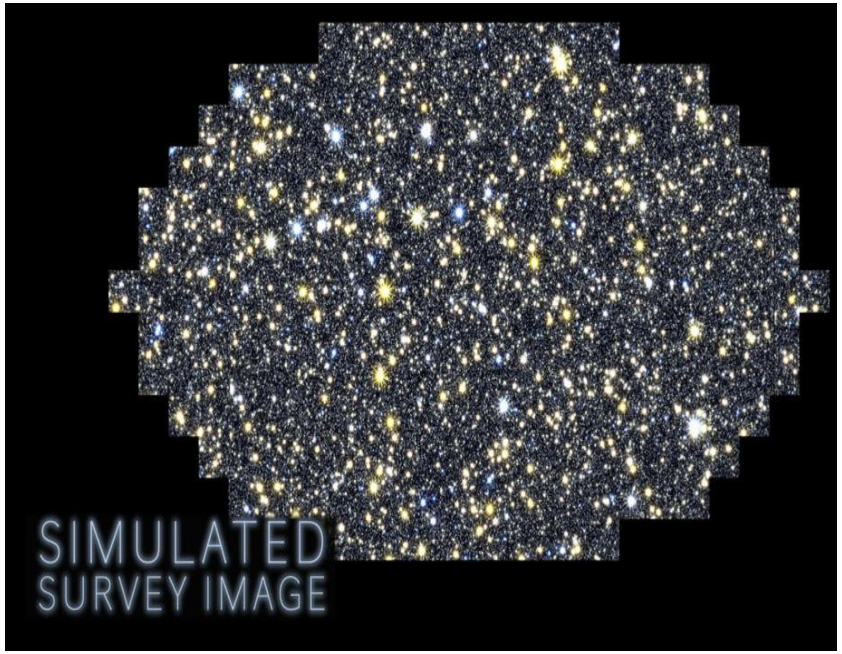
Another Confounding Factor: Binaries

The GBTDS field will have many unresolved binaries.

This will introduce a bias toward assuming larger stars and shallower transits

We still can:

- Analyze the PSF shape for a statistical sample
- Identify shifts in the PSF from Roman astrometry and proper motions
- Compare to expected intrinsic colors (even better with parallaxes)
- Model multi-component stellar fits for our SEDs (computationally expensive)



KIC Pipeline – Brown et al. 2011

- First, ingested the raw photometric catalogs
- Second, estimated and corrected the atmospheric extinction suffered by each measurement, and accounted for interstellar extinction
- Third, combined the calibrated magnitudes with other information (e.g. stellar atmosphere models - Castelli & Kurucz 2004) to estimate the physical parameters of each observed star, including Teff, log(g), [Z], radius R, mass M, and interstellar reddening $E_B{-}V$
- **Last**, it discarded those stars (and putative stars) for which estimates were deemed unreliable.

Reliability– Brown et al. 2011

- For Teff ≤ 5400 K, comparison with asteroseismic results shows that the *distinction* between main-sequence stars and giants is reliable with about 98% confidence.
- On the reliability of their log(Z) estimates: “there is reason to suspect that it is poor”

There were many Pre-Gaia revisions to the KIC as new stellar models and observations became available!

Huber et al. 2014

- Revised properties for 196,468 stars observed by Kepler in Quarters 1–16
- Adopted Dartmouth Stellar Evolution Database isochrones (DSEP, Dotter et al. 2008)
- Considered all published data from: **Asteroseismology**, **Transits**, **Spectroscopy**, **Photometry**, and the KIC
- Used the same reddening model, metallicities, and surface gravities as the KIC

Huber et al. 2014

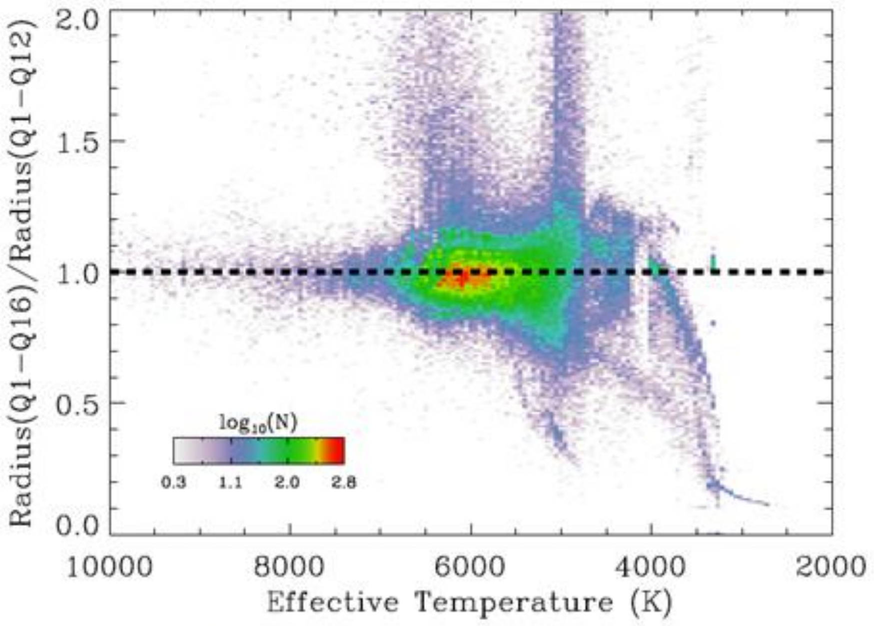


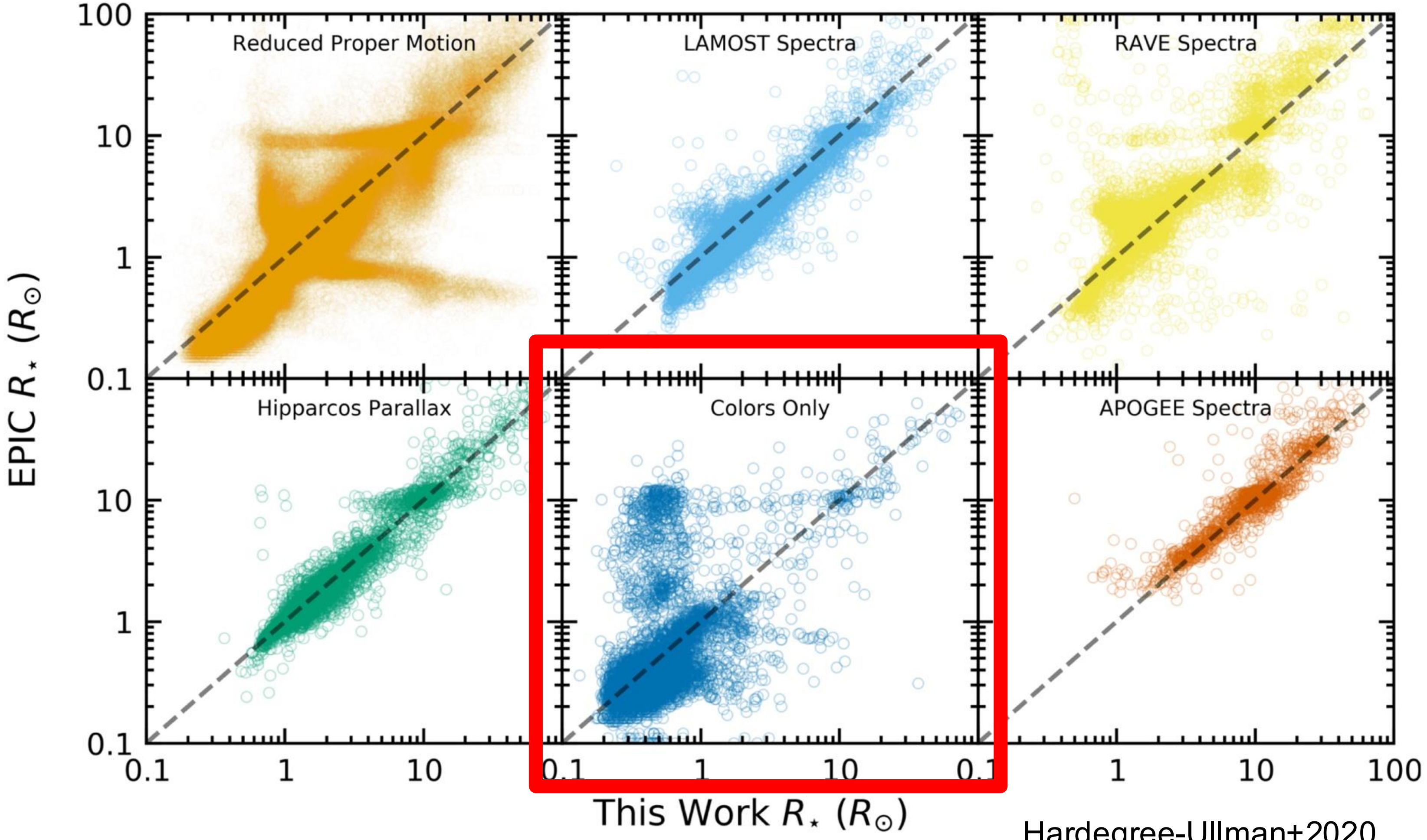
FIG. 13.— Ratio of radii in the current catalog and the radii in the Q1Q12 catalog as a function of effective temperature. Colors denote the relative logarithmic number density of stars as given in the legend.

- Typical uncertainties in derived radii and masses are ~40% and ~20%, with photometric constraints only
- A comparison with the Q1–Q12 catalog shows a systematic decrease in the radii of M dwarfs
- Radii of F–G dwarfs are on average unchanged, with the exception of newly identified giants.
- Ideally, a catalog of Kepler targets should provide the **most accurate stellar properties on a star-by-star basis**, while at the same time being as *homogeneous as possible*
- **Future efforts**: using proper motions or additional colors

K2 and TESS Went Through a Similar Process

The addition of Gaia DR2 parallaxes were able to uncover even more offsets in stellar properties based primarily on photometry.

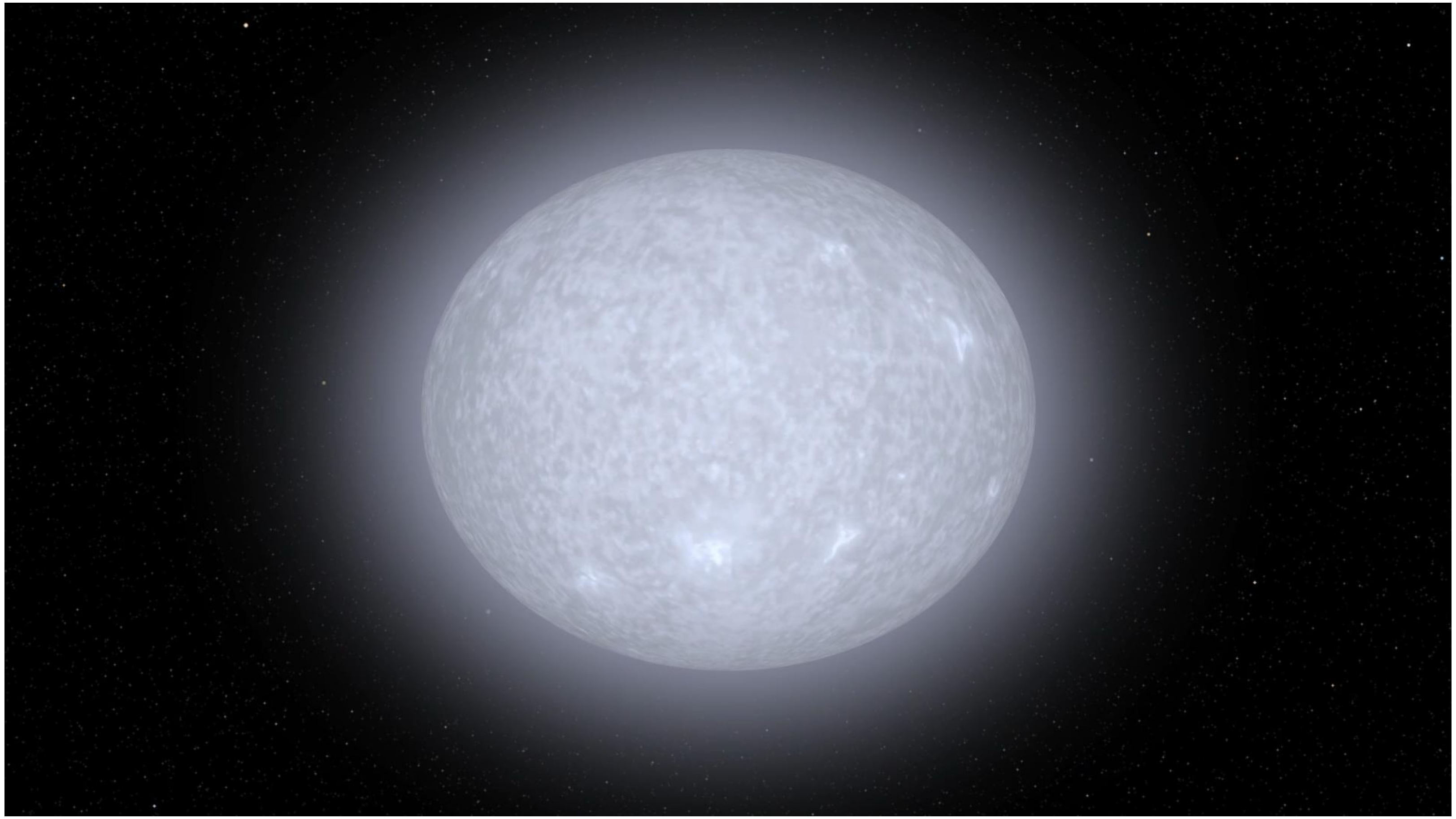
So what additional information will we have with Roman?



Hardegree-Ullman+2020

Roman will do asteroseismology!

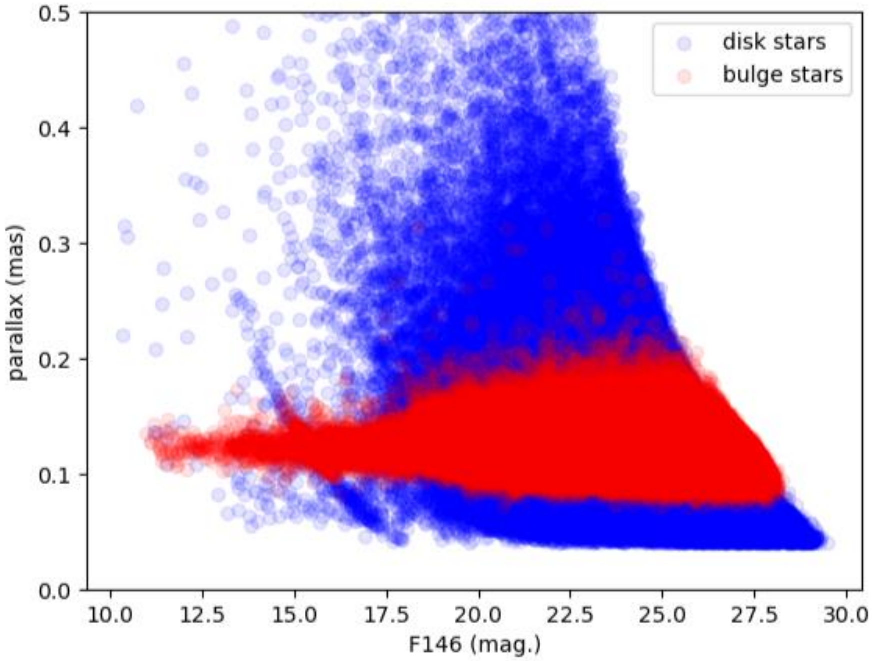
We'll hear more from Prof. Marc Pinsonneault next!



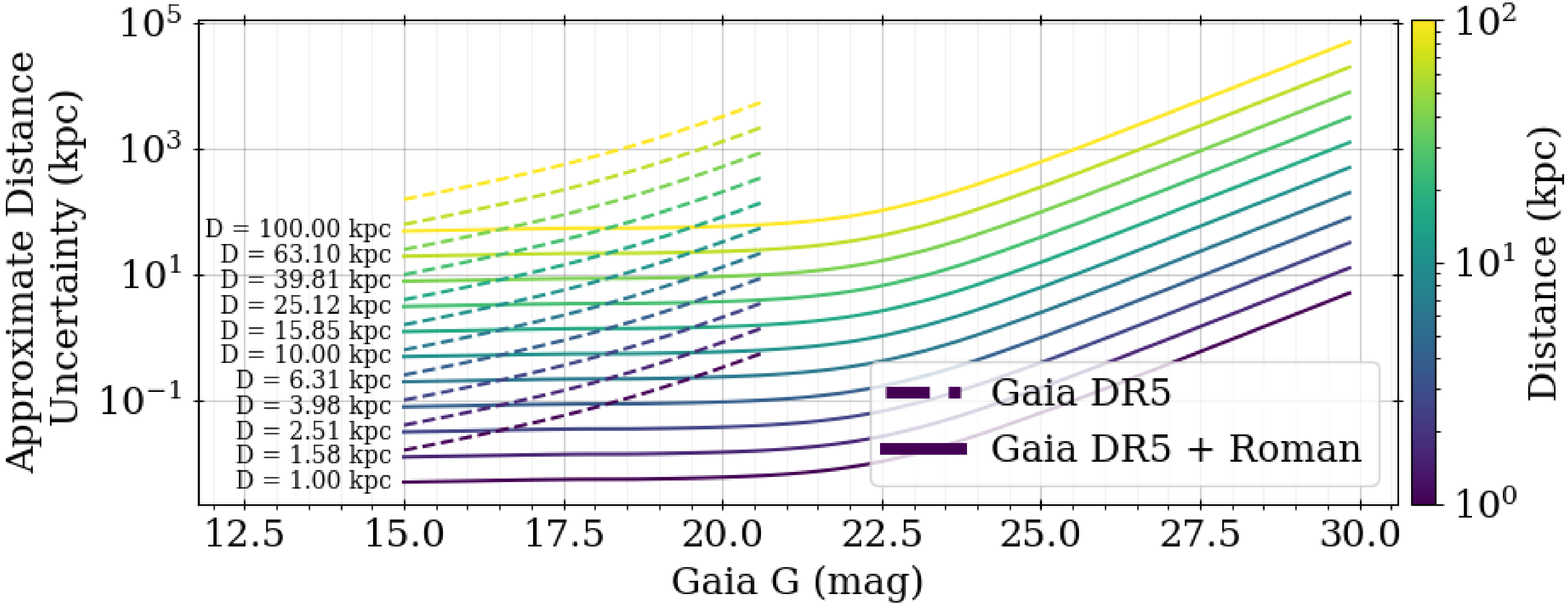
Credit: NASA's Goddard Space Flight Center

Roman will measure proper motions!

- We'll get proper motions which can help differentiate between bulge and disk stars!
  - You got to try this out in Hands On Session II
- Knowing which population our stars are coming from can help us constrain our stellar models.



Roman will measure parallaxes!



McKinnon et al. 2026

Conclusions

- Roman will discover the most distant planets ever! We will need to characterize their host stars!
- We can combine photometry, stellar models, extinction maps and eventually parallax measurement to provide estimates of stellar properties like radius and temperature.
- Our ability to characterize Roman transiting planet host stars will improve with time as it measures stellar proper motions and parallaxes.