MEASURING HOT JUPITER OCCURRENCE RATES IN HIGH-α STELLAR POPULATIONS WITH DECam

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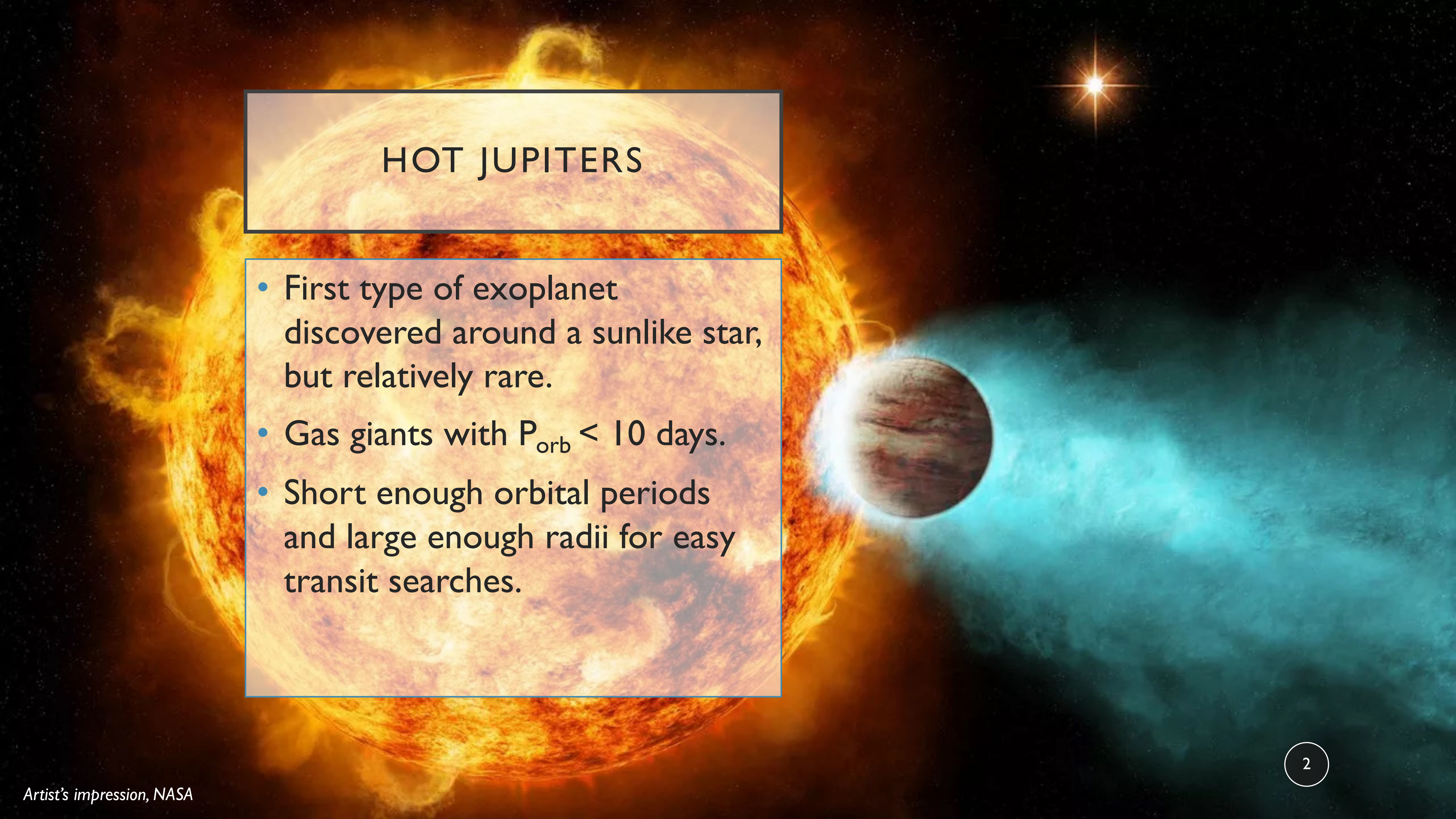
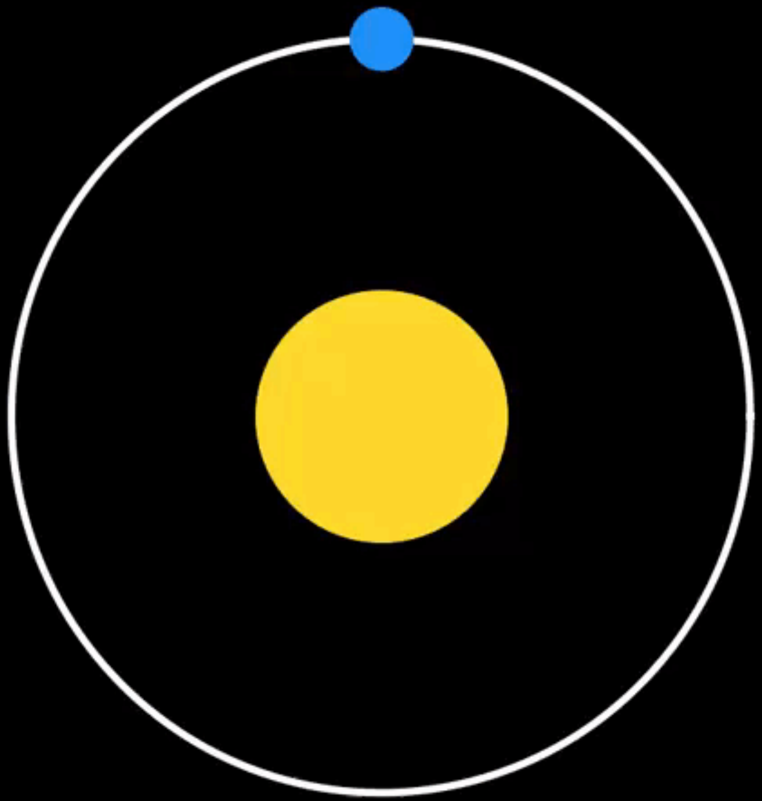
HOT JUPITERS

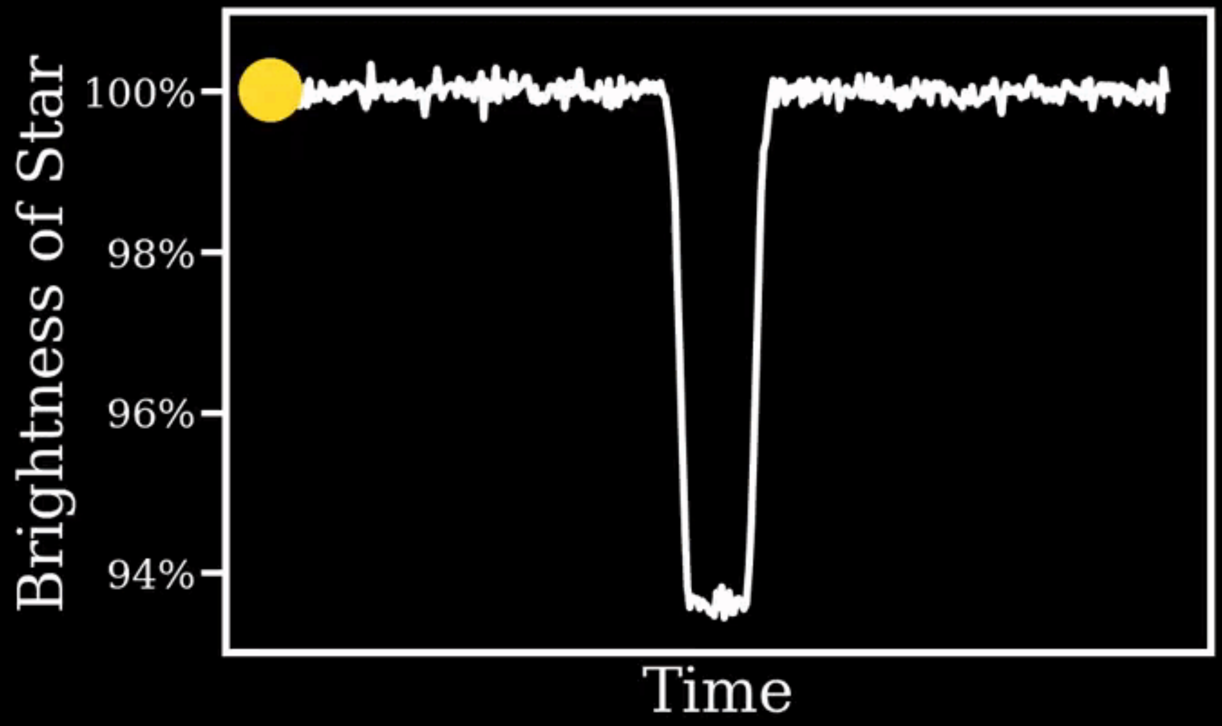
- First type of exoplanet discovered around a sunlike star, but relatively rare.
- Gas giants with $P_{orb} < 10$ days.
- Short enough orbital periods and large enough radii for easy transit searches.

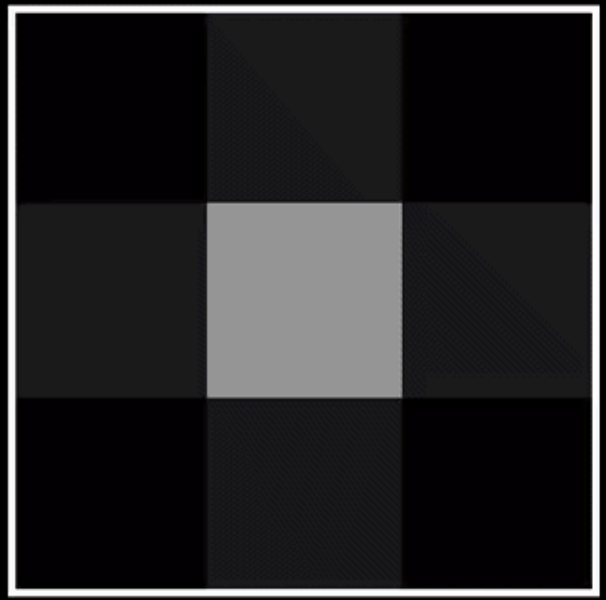


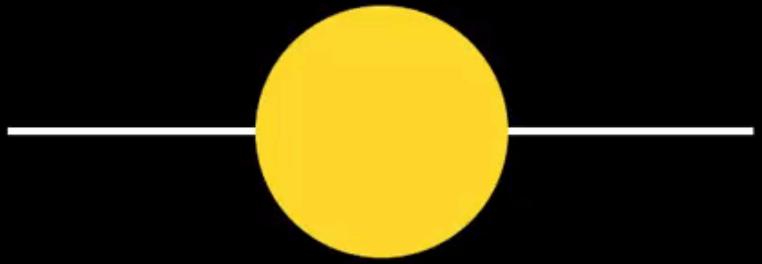
Artist's impression, NASA

Alysa Obertas (@AstroAlysa)



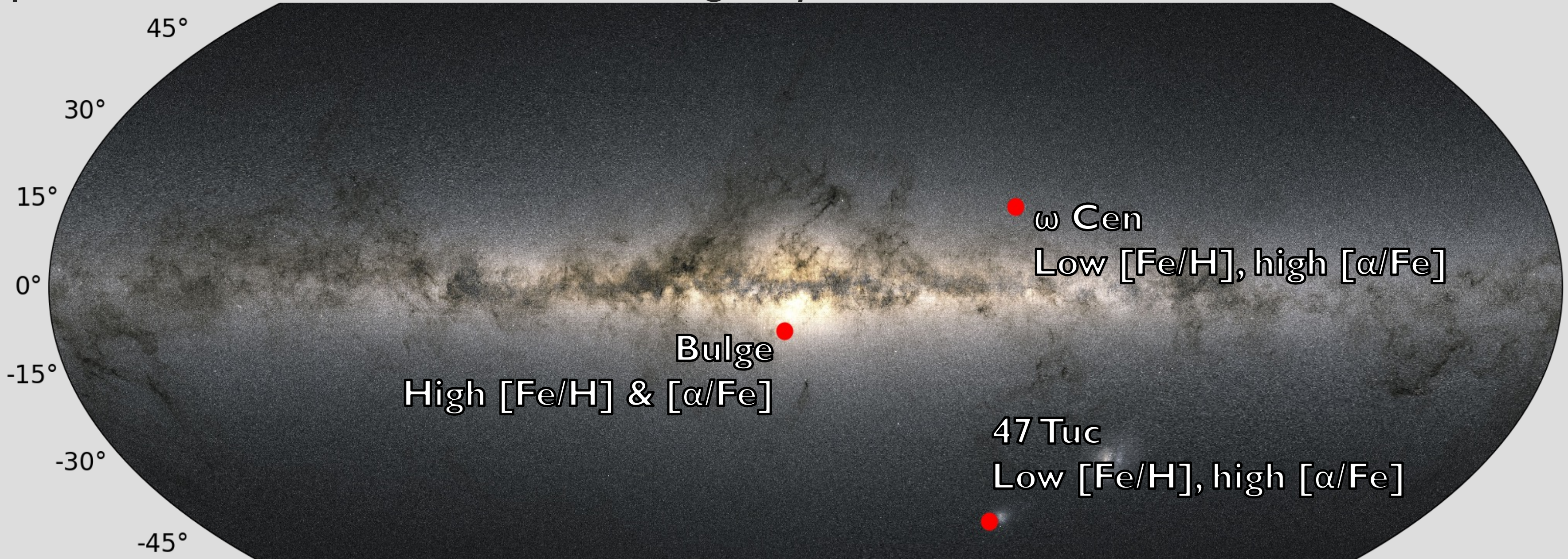






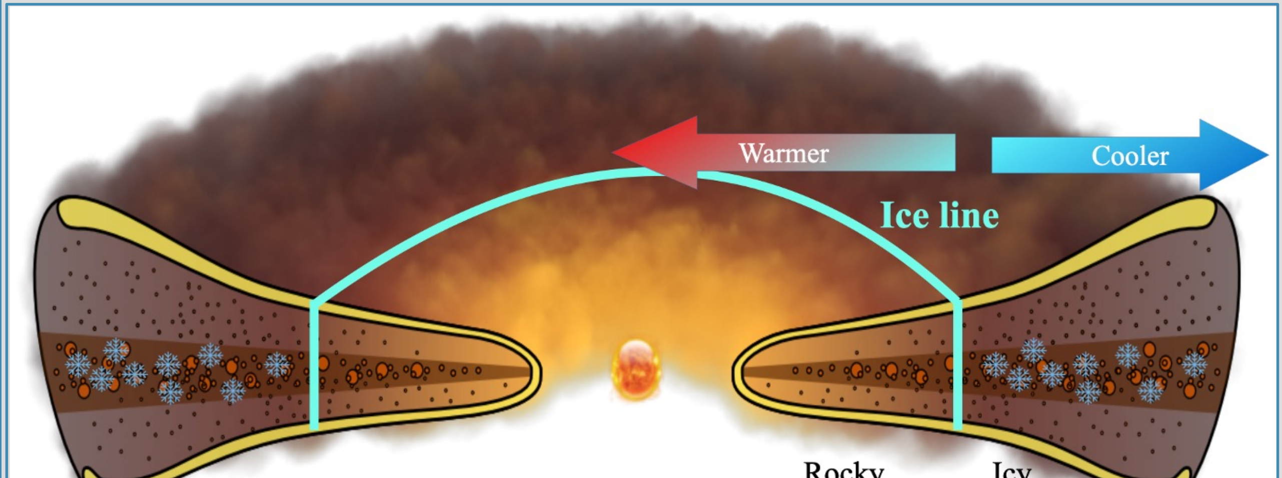
MISHAPS
Multiband Imaging Survey for High-Alpha PlanetS

- Find and characterize candidate transiting hot Jupiters and their host stars.
- Focus on those with $0.8 < P < 3.4$ days.
- Measure a hot Jupiter occurrence rate for each population.
- Compare to thin disk rates found with, e.g., *Kepler*.



WHY α-ABUNDANCE?

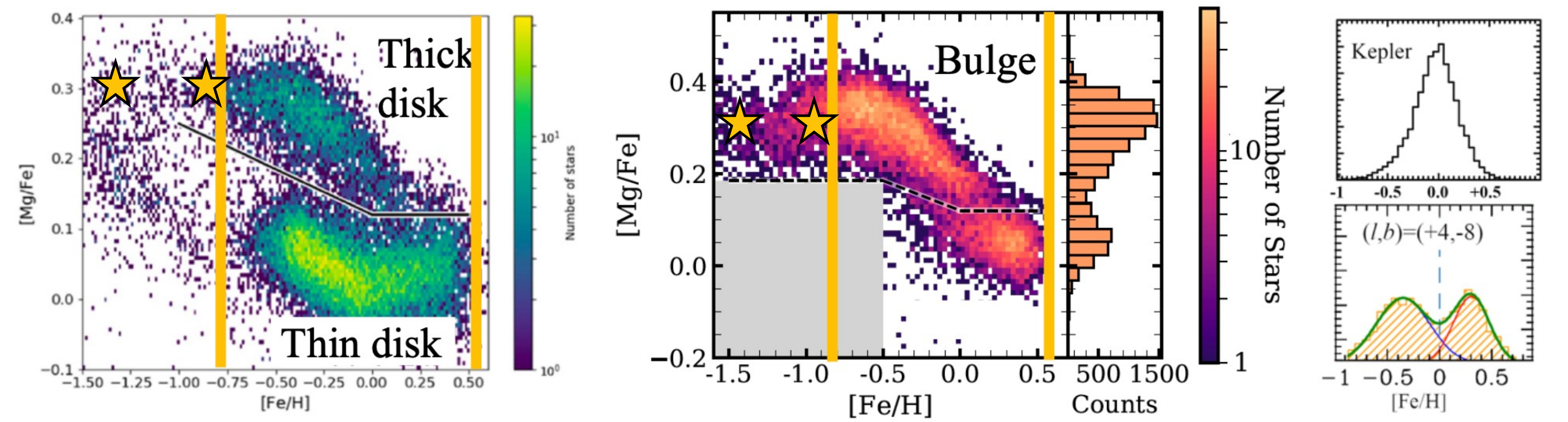
- Far enough out, the protoplanetary disk contains ices.
- Forming a giant planet requires gathering larger amounts of material before the disk dissipates.
- Gathering ices aids in mass gain.
- Ice = Oxygen = [α/Fe].
- So, higher [α/Fe] could reasonably affect formation rates.

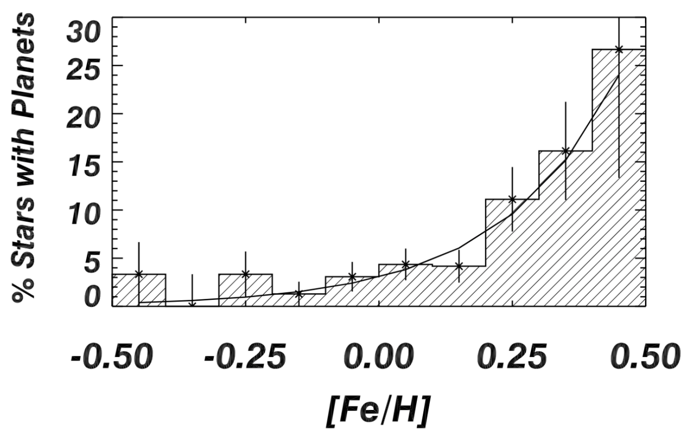


Credit: T. Birnstiel Annotations: M. Penny

WHY α-ABUNDANCE?

- Giant planet formation strongly correlated with metallicity.
  - $f_{GP} \propto 10^{2.0\,[Fe/H]}$ (Fischer & Valenti, 2005)
  - $f_{GP} \propto 10^{1.2\,[Fe/H]}$ (Johnson et al., 2010)
- [Fe/H] and [α/Fe] are strongly correlated in disk stars, so it's difficult to disentangle which increases the occurrence rate with current demographics.
- Hypothesis: α-abundance [α/H]=[α/Fe]+[Fe/H] more important than [Fe/H] alone.

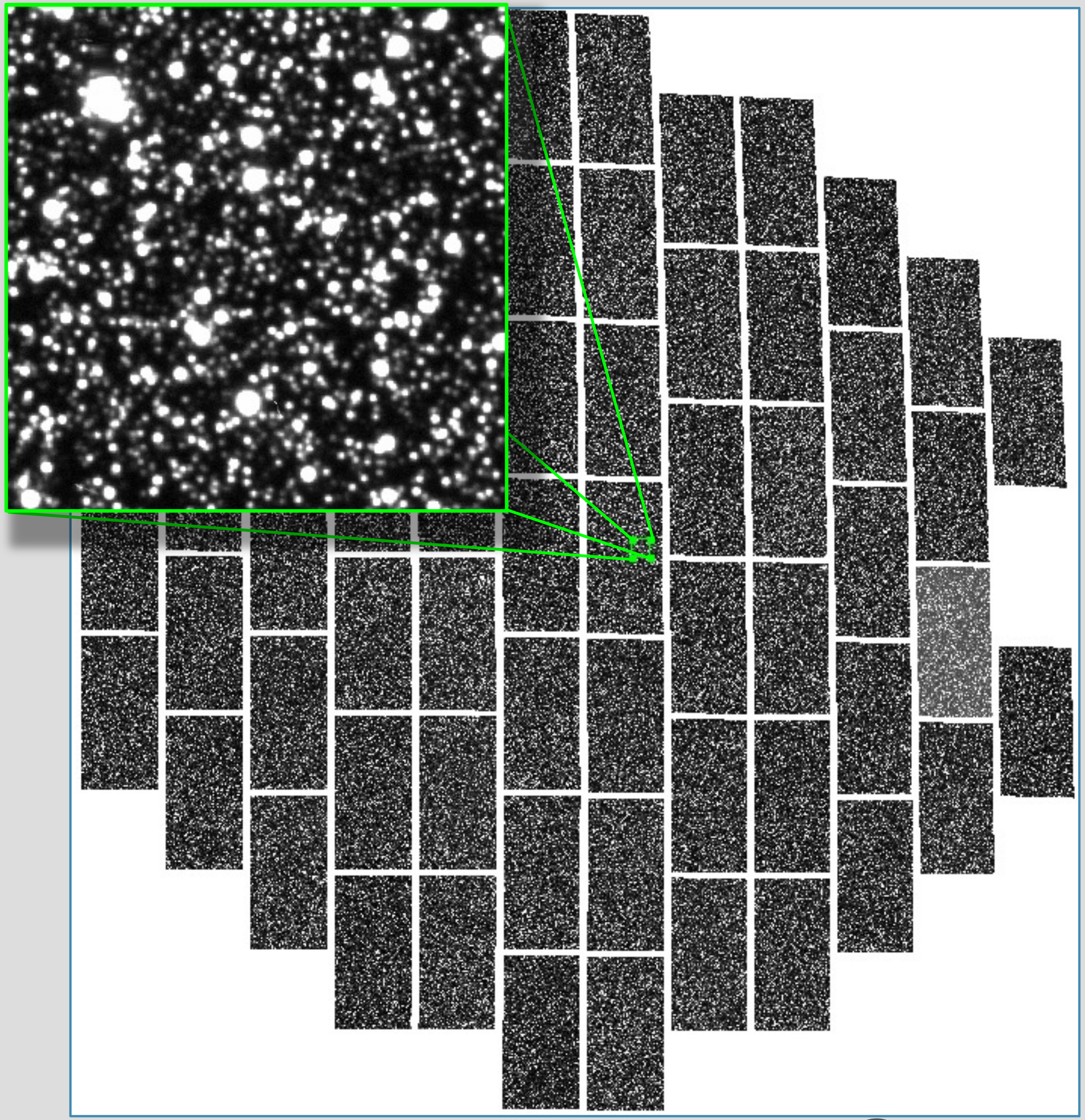




Left: *Bulge [Fe/H] and & [α/Fe] values from Dong et al. 2014, Griffith et al. 2020, Weinberg et al. 2019, & Zoccali et al. 2017; GC [Fe/H] & [α/Fe] values from Cordero et al. 2014, Forbes & Bridges 2010, and Johnson & Pilachowski 2010*
Right: *Fischer & Valenti 2005*

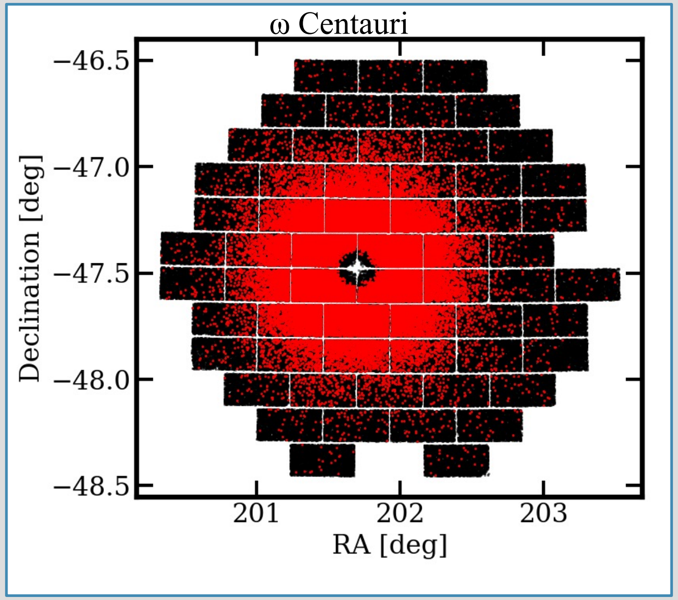
WHY DECAM?

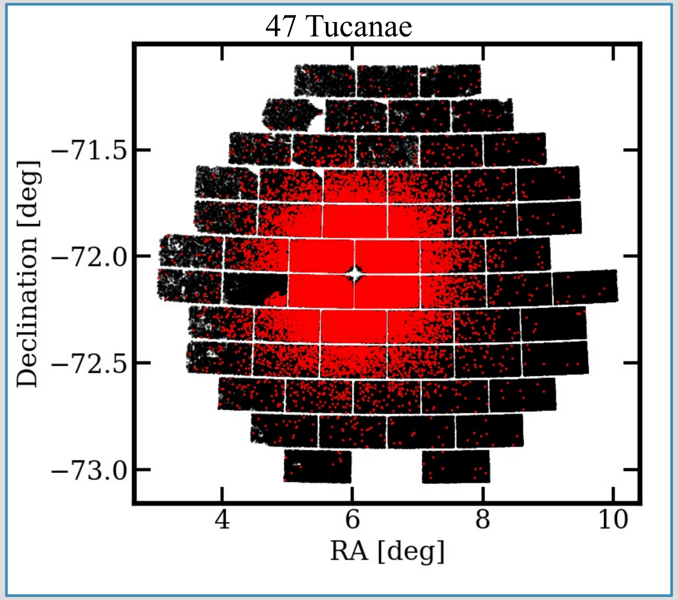
- To get an occurrence rate with 10% uncertainty, we need ~100 hot Jupiters.
- To get ~100 hot Jupiters, we need photometry with 1% precision on ~1 million stars.
- Faint targets mean follow-up is tough.
- DECam's large FOV, high z sensitivity, and fast filter change all us to do most of the traditional photometric follow-up as part of the survey.



WHY GLOBULAR CLUSTERS (AGAIN)?

- Studies such as Gilliland et al. (2000) returned no hot Jupiter candidates in 47 Tuc, ω Cen, and other GCs.
- Masuda & Winn (2017) finds that only 2.2 planets would be expected in 47 Tuc if its occurrence rate matched *Kepler's*.
- Previous studies did not have the sample size or sensitivity to rule out *Kepler*'s rate with sufficient confidence.
- With DECam's sensitivity and FOV, we expect to detect $\mathcal{O}$ 10 planets per cluster with 95% confidence.
- Okay, so why the difference in survey design then?
  - Bulge – little hope of follow-up, so more nights needed to ensure multiple transits and good chromatic measurements to rule out false positives $\mathcal{O}$100-1000 candidates.
  - Clusters - brighter stars and fewer expected candidates mean we can relax some measurement constraints, and thus require fewer nights of data.





THE MISHAPS PIPELINE

Process Images

- Create Reference Images
- Perform Difference Imaging

Calibrate Photometry

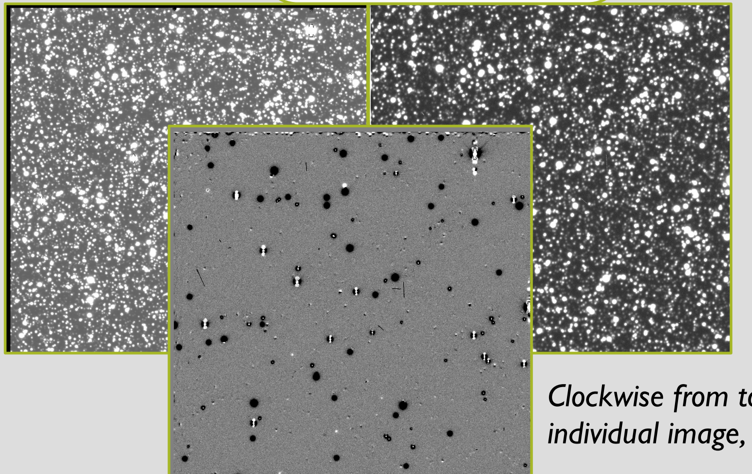
- De-trend with Vartools

Perform Transit Search

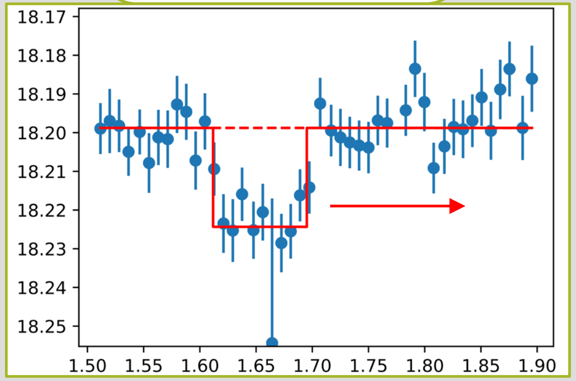
- Search over grid of transit centers and durations with sliding "Boxcar"

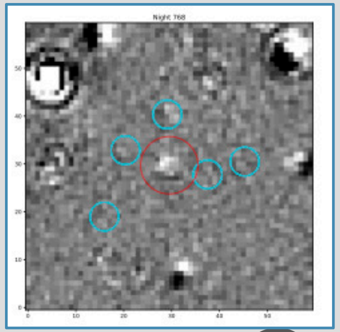
Vet Candidates

- Lightcurves
- CMD
- Stacked Difference Images
- Periodograms & Folded Lightcurves



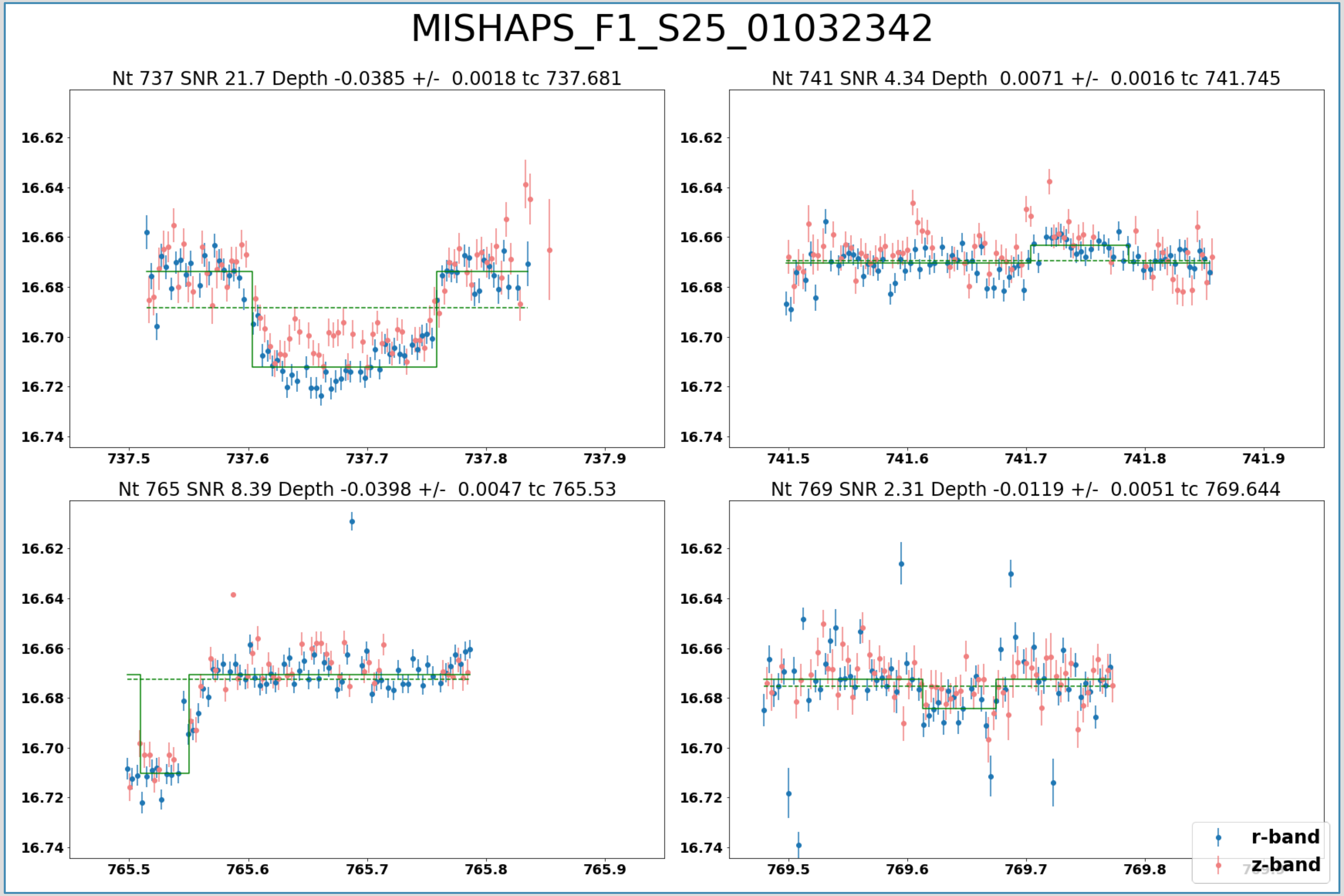
Clockwise from top left: reference image, individual image, difference image



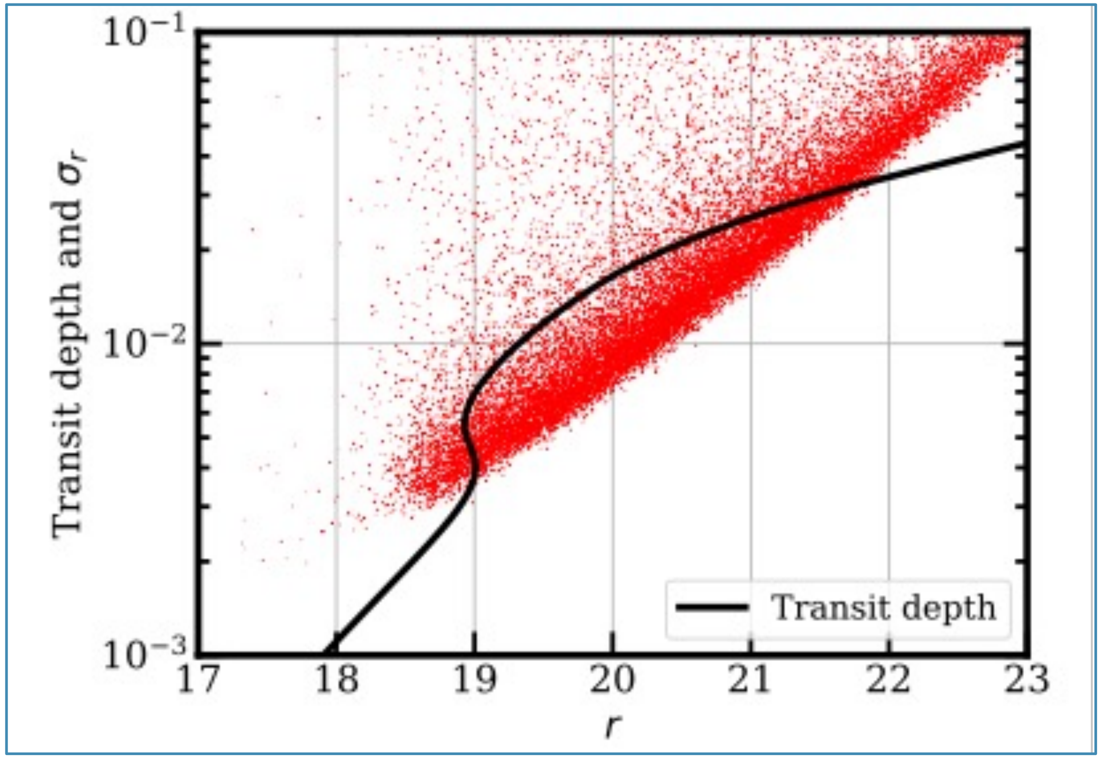


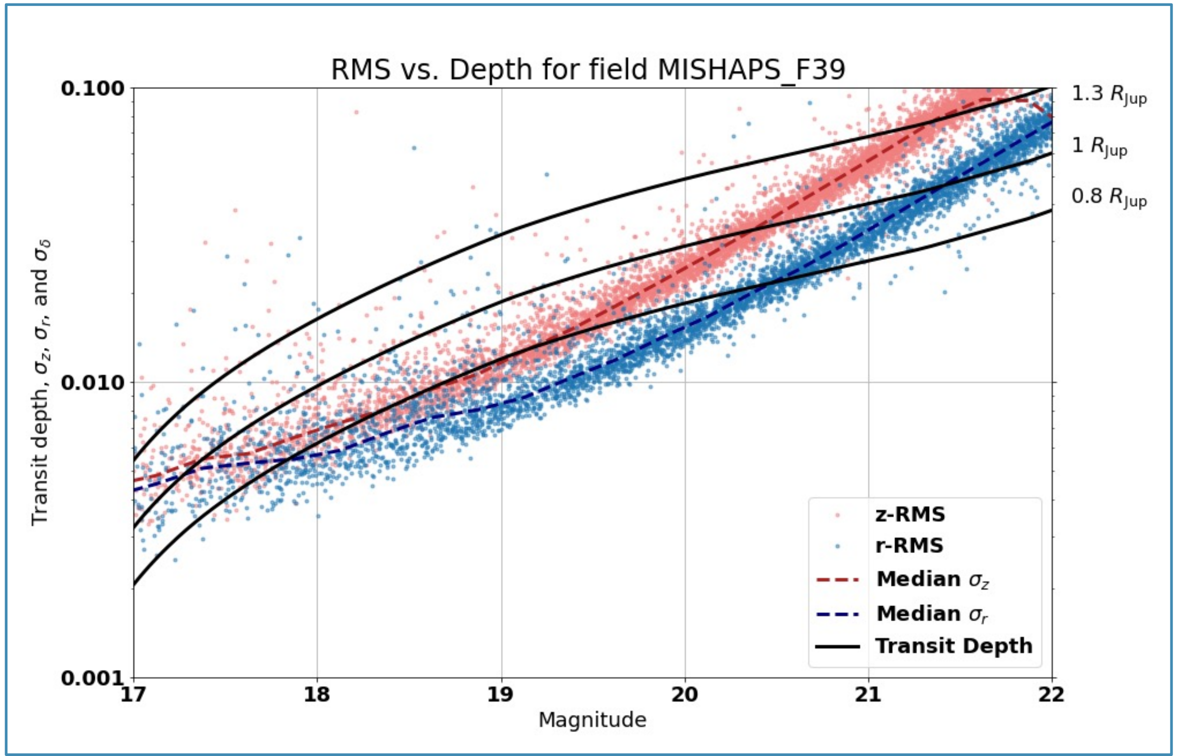
FALSE POSITIVES

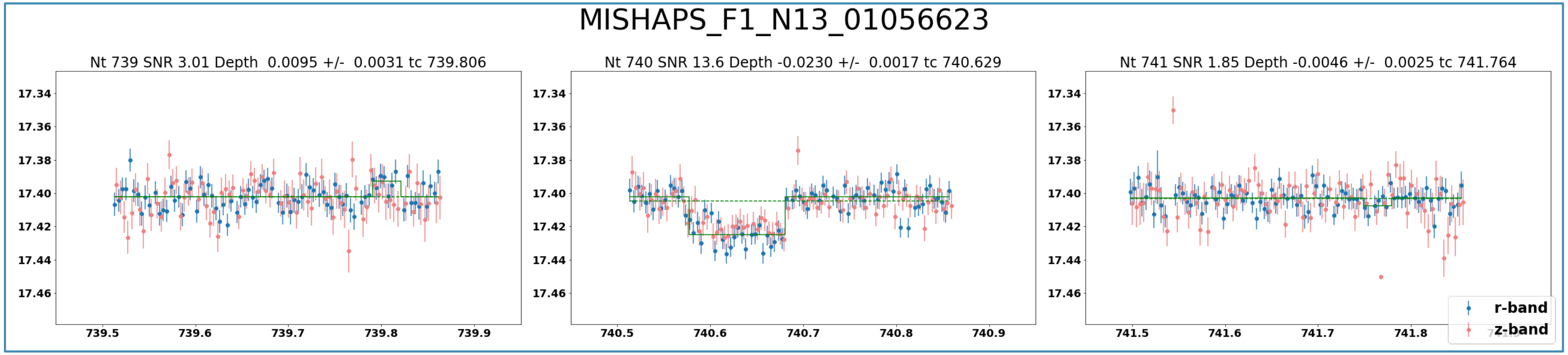
- Signals that appear to be transits, but aren't
- Sources include systematics, bad seeing
- Largest source is various eclipsing binaries



Photometric Precision

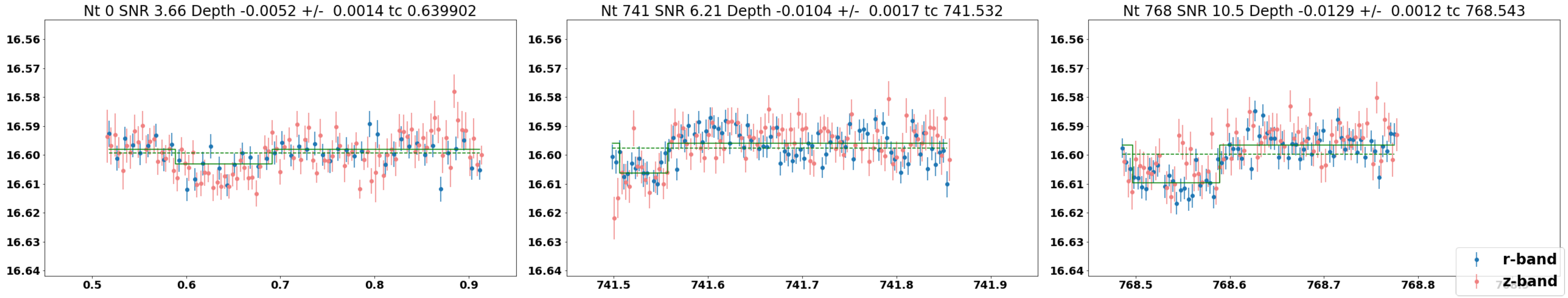




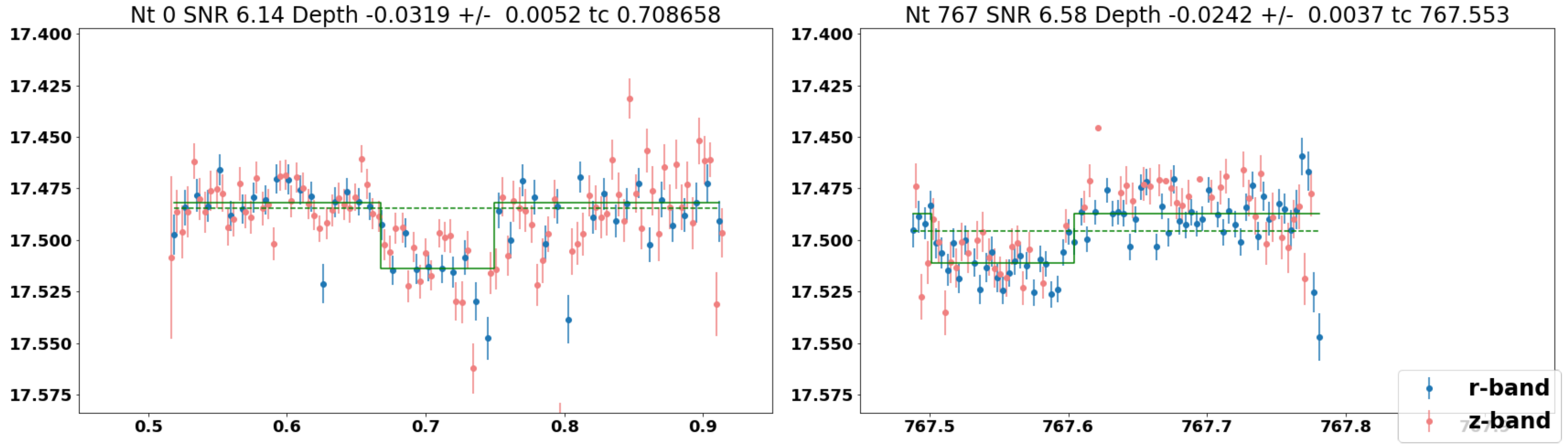


FIRST BULGE CANDIDATES

MISHAPS_F1_N13

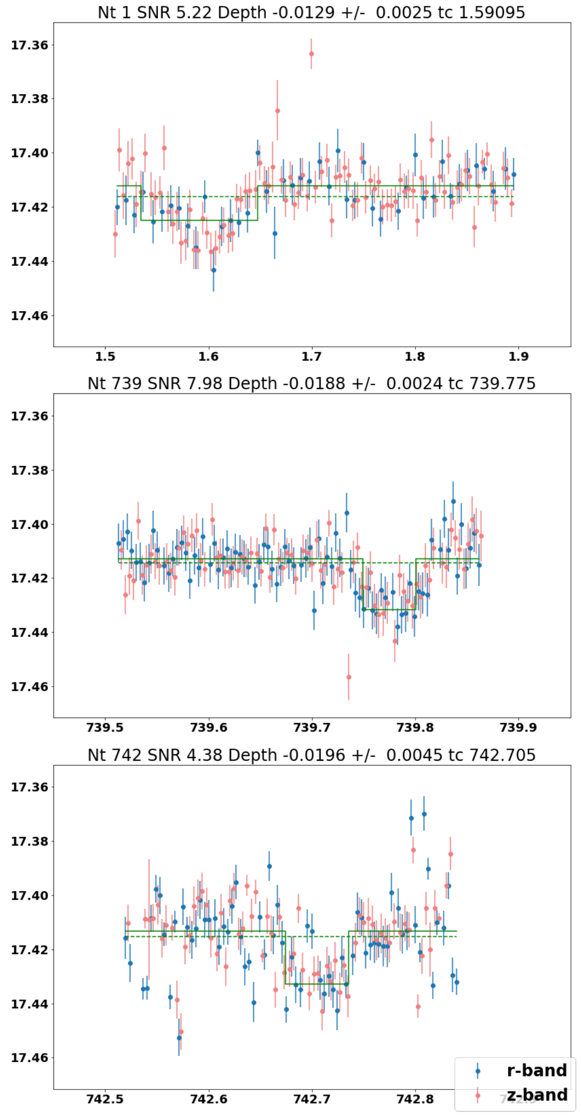


MISHAPS_F1_S25



“BULGE” RESULTS

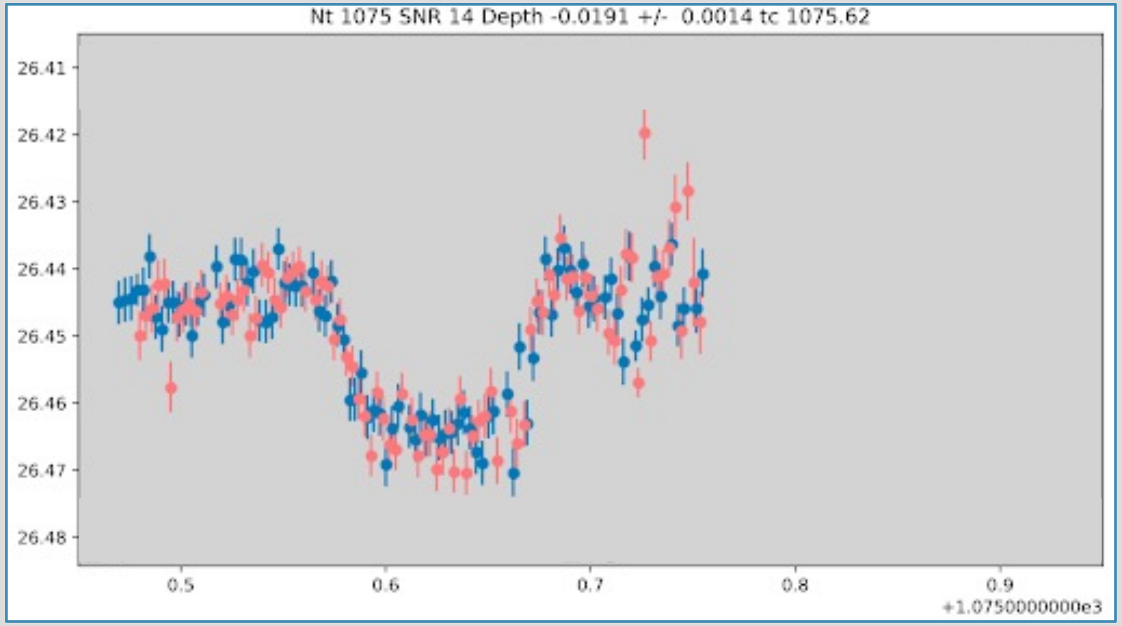
MISHAPS_F1_N18



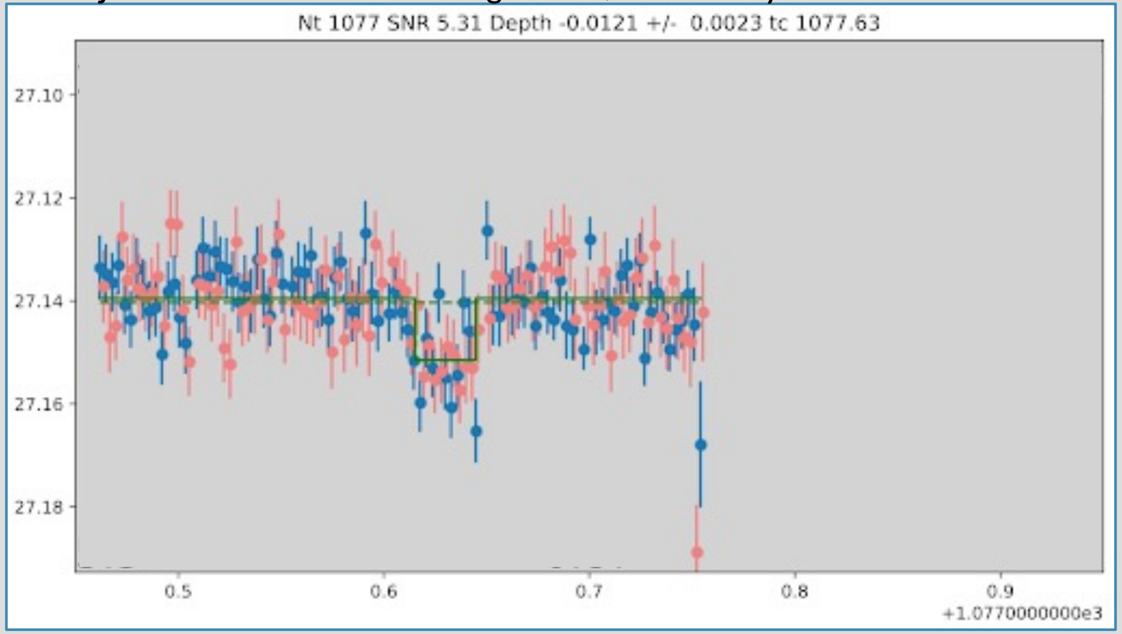
MISHAPS_F1_N19

ω CEN PRELIMINARY RESULTS

- Haven't had the data long enough for a thorough search.
- Preliminary work done by REU student Ethan Fahimi (OSU senior).
- Estimated occurrence rate to be <0.004 planets per star at 95% confidence for a single chip (~7,000 stars).

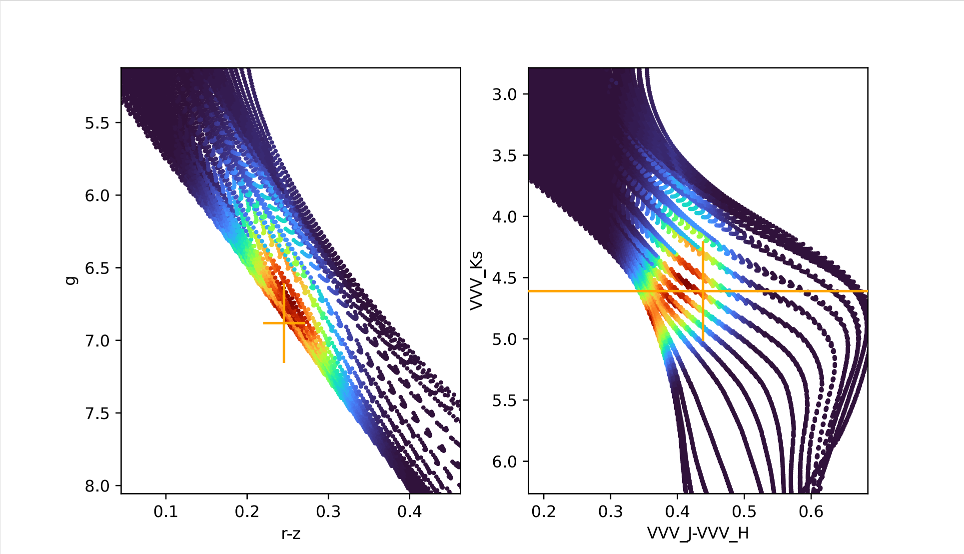


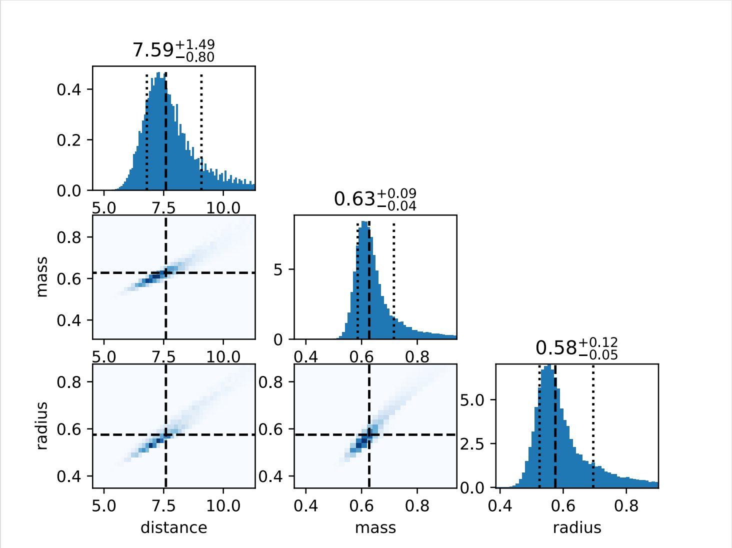
Injected transit in an ω Cen lightcurve, returned by search



Real detection in an ω Cen lightcurve (further investigation needed to determine if it's a real transit)

SOURCE CHARACTERISATION WITH SED FITTING





- It is easy for one Star, but we want to know it for $\mathcal{O}$(1Mil) stars
- Fit theoretical isochrones to:
  - DECam magnitudes: (u) g r i z Y
  - *NIR* VVV magnitudes: J, H, Ks

- Estimates:
  - stellar properties (radii, masses, metallicities)
  - distances & extinctions
  - likelihood that a star belongs to bulge or disk population
- Work in Progress:
  - automatic removal of outliers
  - more realistic distance priors

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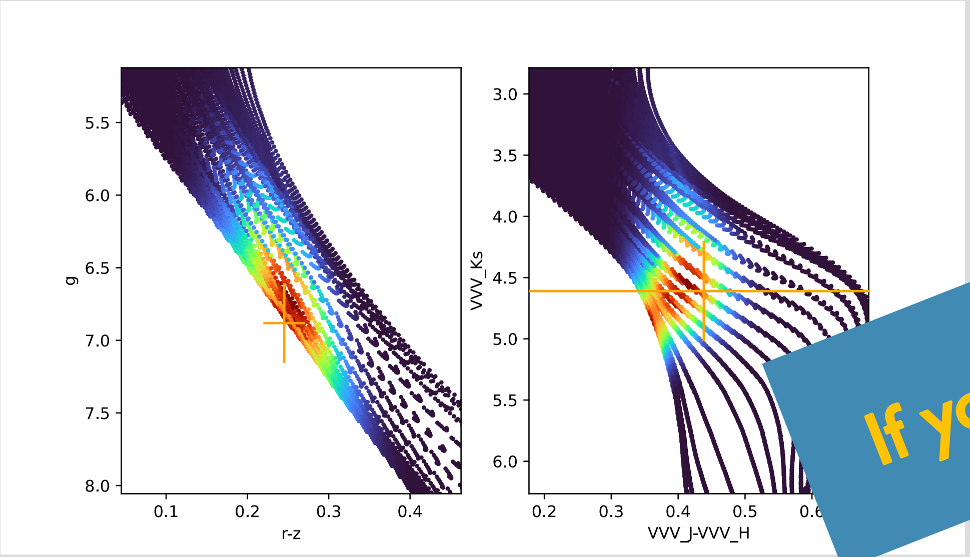

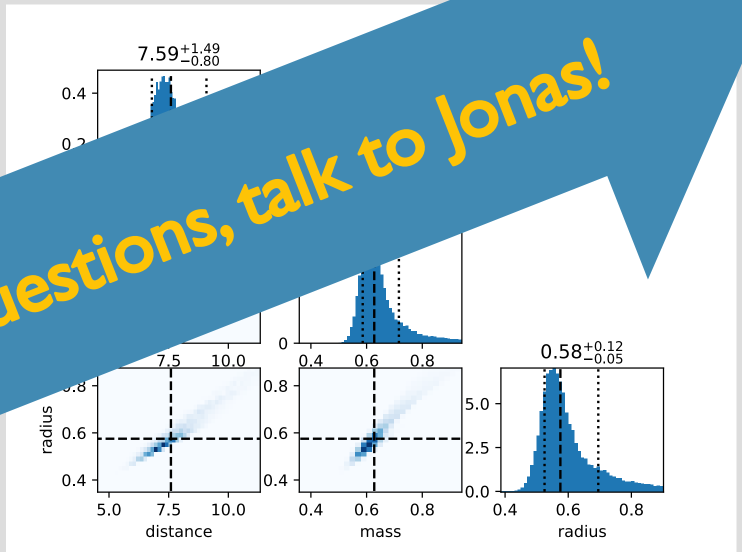

If you have questions, talk to Jonas!

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PROJECT TIMELINE

- June-August 2019 – Bulge observations
- 2020 - ☹
- July & August 2021 – Bulge observations
- June 2022 – ω Cen observations
- November 2022 – 47 Tuc observations scheduled
- End of year – Publish ω Cen results
- 6+ months – Publish 47 Tuc results
- Some time in 2023 – final Bulge observations
- Spring 2024 – Publish final occurrence rates, defend, & graduate