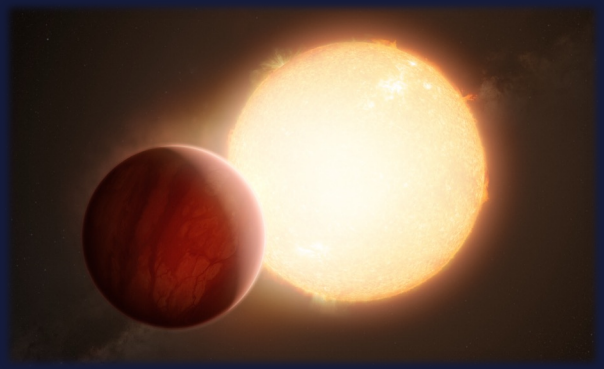
Towards Hot Jupiter Occurrence Rate and Atmospheric Characterization Beyond the Solar Neighborhood



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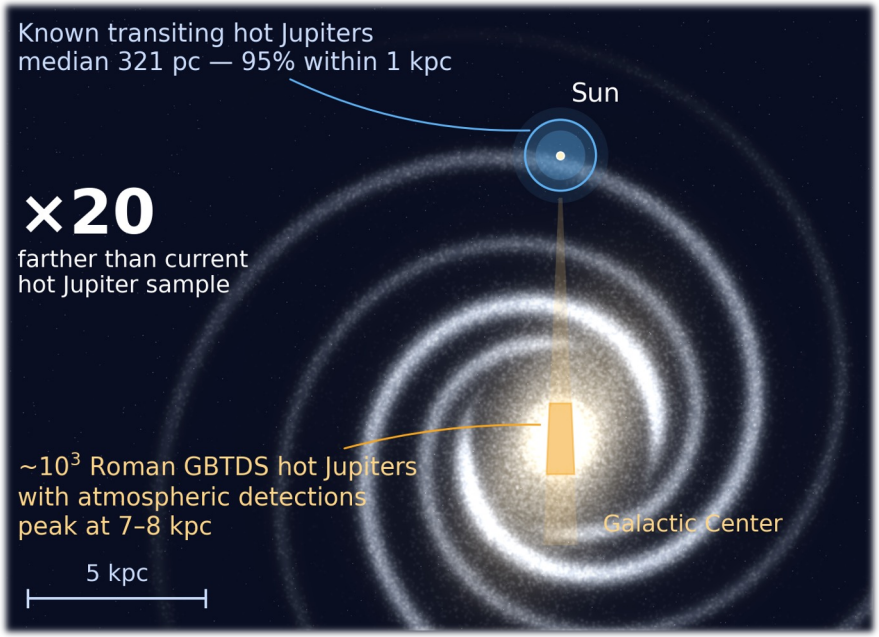
MOTIVATION

Hot Jupiters across the Galaxy

- Roman GBTDS will reveal many HJs, but confirmation is challenging.
- Thermal emission (eclipse + phase curve) can:
  1. Confirm/validate planets photometrically, leading to HJ occurrence in the metal-rich bulge.
  2. HJ atmosphere census beyond the solar neighborhood.



ANALYSIS · STEP 1 OF 3

1

Stellar population & hot Jupiter occurrence

- Besançon model:
  37.5M AFGKM dwarfs, 6 fields, F146 < 22.
- Occurrence rates ($P \leq 3$ d, $R > 8\ R_{\oplus}$):
  - Method A — Cui et al. 2026 (conservative).
  - Method B — Beleznay & Kunimoto 2022 (upper bound).
- Metallicity boost $10^{3.4 \cdot [Fe/H]}$, capped at +0.4.
- Wilson et al. 2023 catalog corrections:
  Extinction ($R_V = 2.5$), binarity, bulge IMF.
- Cui et al. 2026 period distribution; $p_{tra} = R_{\star}/a \approx 10–23\%$.

ASSUMPTIONS

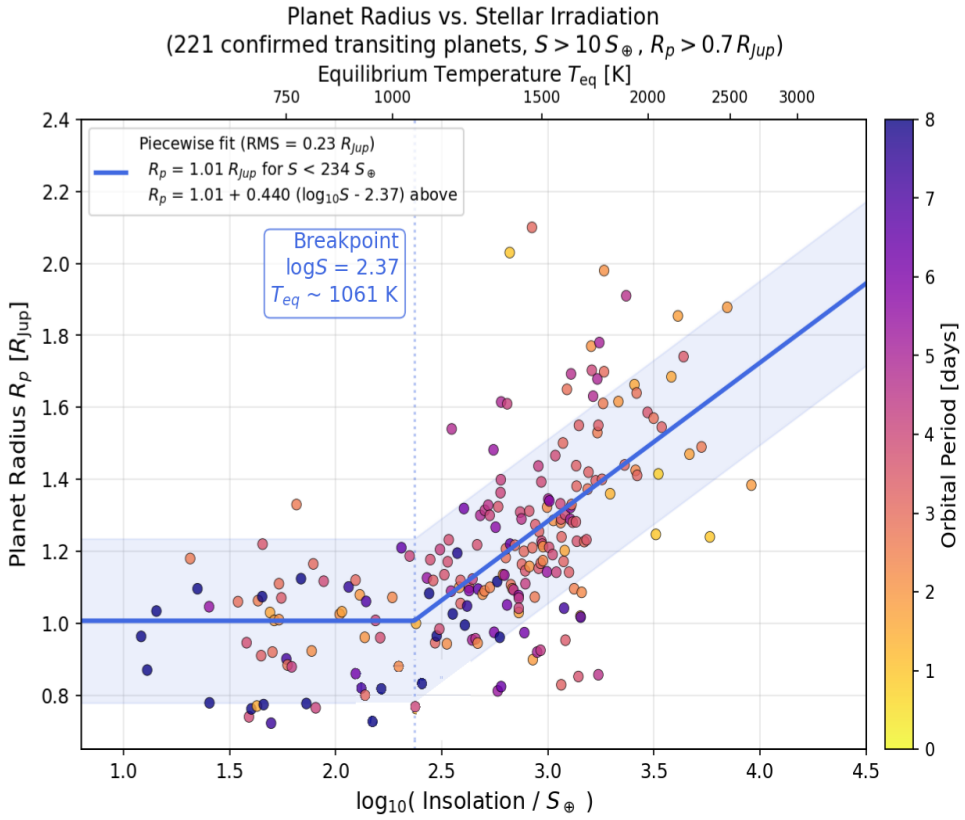
- ≤ 1 HJ per star.
- Local rates hold in the bulge.
- $P \leq 3$ d only.

ANALYSIS · STEP 2 OF 3

2

Thermal emission & planet radius model

- Day/night temperatures: Cowan & Agol 2011.
- Nightside floor ~1100 K (Keating et al. 2019).
- R_p from irradiation fit to 221 HJs (right).
- Real F146 effective area (18 WFI SCAs).
- $A_{therm} = (R_p/R_\star)^2 \cdot (B_{day} - B_{night})/2B_\star$
- $\delta_{ecl} = (R_p/R_\star)^2 \cdot B_{day}/B_\star$.
- Assumptions:
  - Blackbody,
  - $A_B = 0.1$,
  - No reflection in F146,
  - No clouds.

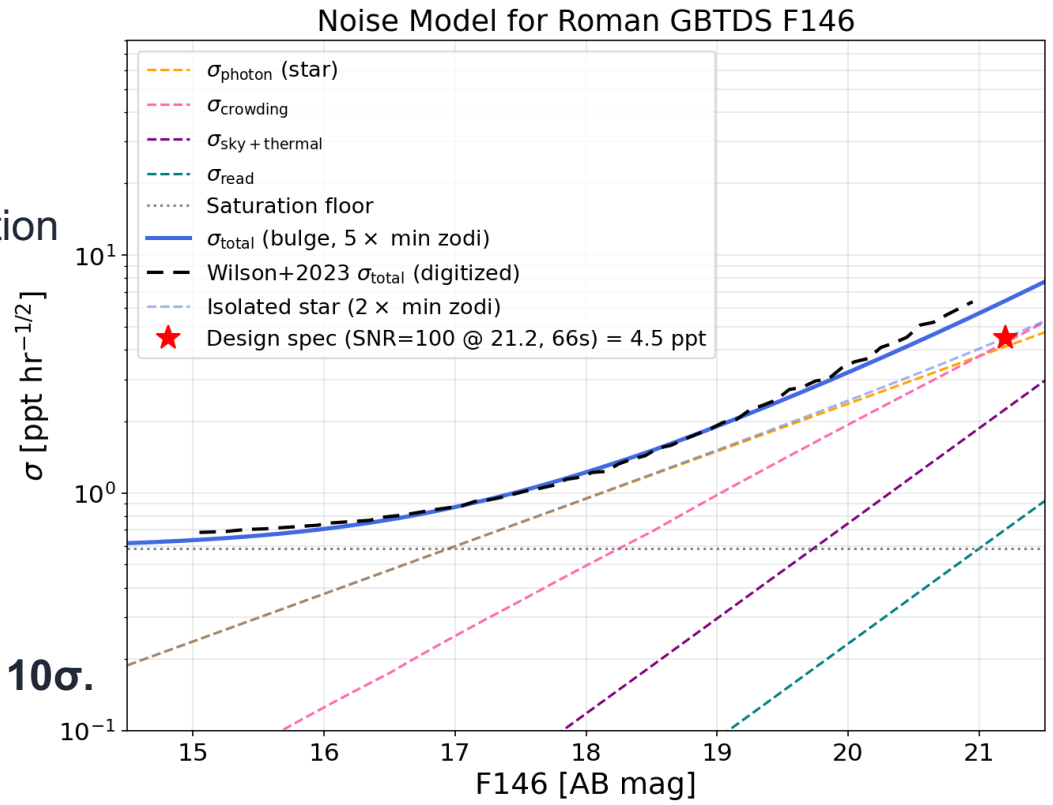


ANALYSIS · STEP 3 OF 3

3

Photometric noise & detection criteria

- Anchored to design spec:
  S/N = 100 at F146 = 21.2 and exp = 66 s.
- Noise: photon + read + background + saturation floor.
- Crowding Γ_C: extra noise + dilution $(1 - \Gamma_C)$.
- 6 seasons → N_{obs} = 45,306 epochs.
- $S/N_{therm} = A_{therm}(1-\Gamma_C)/\sigma_{cad} \times \sqrt{(N_{obs}/2)}$.
- $S/N_{ecl} = \delta_{ecl}(1-\Gamma_C)/\sigma_{cad} \times \sqrt{N_{in\text{-}ecl}}$.
- **Detection: phase curve AND eclipse ≥ 5σ, 10σ.**



RESULTS · 6-SEASON SCENARIO

Predicted yield: a thousand-planet thermal-emission sample

7,782 – 11,714

transiting HJs (F146 < 22)

1,990 – 2,940

phase curve AND eclipse > **5σ**

1,170 – 1,714

phase curve AND eclipse > **10σ**

Ranges span Method A (conservative) to Method B (upper bound) occurrence rates.

Spectral type	A	F	G	K	M
Both > 5σ (A / B)	19	159	**1,528 / 2,330**	283 / 432	< 1
Both > 10σ (A / B)	17	116	**974 / 1,485**	63 / 96	< 1

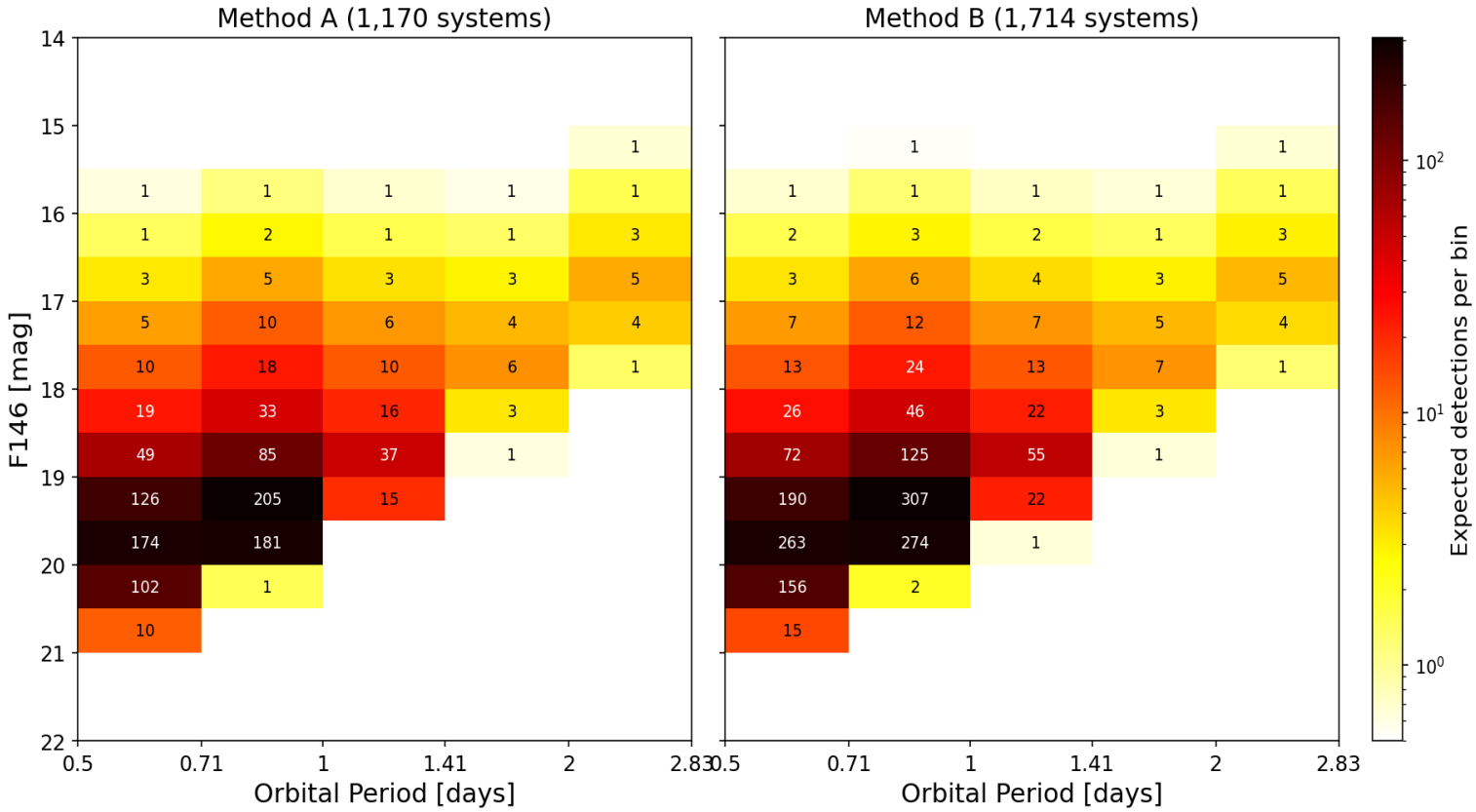
≈80% G dwarfs

RESULTS · 6-SEASON SCENARIO

Where the detections live: period vs. brightness

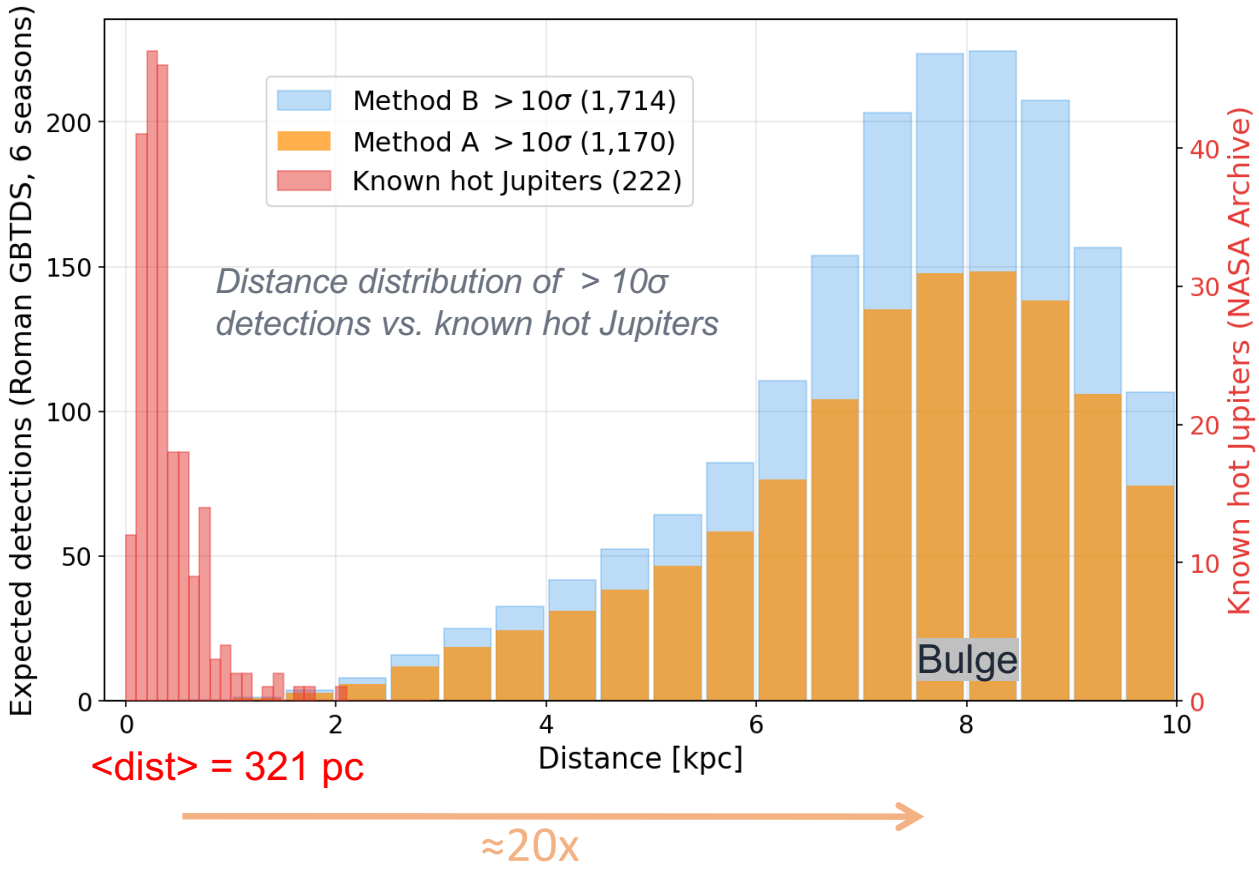
Expected > 10σ detections per (P, F146) bin.

Peak at:
P < 1 d and F146 ≈ 18–20.5.



RESULTS · 6-SEASON SCENARIO

A hot Jupiter sample in the Galactic bulge



FALSE POSITIVES

Telling planets from impostors

Hot Jupiter
$\delta_{ecl}/\delta_{tra} \sim 10^{-3}$–$10^{-1}$, falls with period.

Thermal cos φ only.

M-dwarf companion
$\delta_{ecl}/\delta_{tra} \approx 0.1$, flat in period.

Strong ellipsoidal + beaming.

Blended G+K EB
Secondary too deep: $\delta_{ecl}/\delta_{tra} \approx 0.4$.

Residual ellipsoidal.

(a) Eclipse-to-transit depth ratio; (b) ellipsoidal & beaming relative to thermal; (c) example phase curves at P = 1.2 d.

CAVEATS

What could move these numbers

White-noise assumption

Red noise from variability & systematics — main source of optimism.

Occurrence extrapolation

Local rates + β = 3.4 boost ($10^{\beta \cdot [Fe/H]}$) assumed to hold in the bulge.

Model simplifications

Circular orbits; thermal-only blackbody; P ≤ 3 d.

7,782 – 11,714
transiting HJs (F146 < 22)

1,990 – 2,940
phase curve AND eclipse **> 5σ**

1,170 – 1,714
phase curve AND eclipse **> 10σ**

EXTENDED & FOLLOW-UP STUDIES

Beyond the yield estimate

- Red-noise injection–recovery simulations.
- Extend to $P \leq 10$ d.
- Ensemble atmospheric inference: ε and albedo distributions.
- Occurrence vs. [Fe/H] and Galactic population (disk vs. bulge).
- Hot Jupiter eccentricities from eclipse phase and duration.
- Atmospheric variability: season-to-season changes in phase curves and eclipses.

SUMMARY

The first hot Jupiter atmosphere census beyond the solar neighborhood

- End-to-end yield model: Besançon populations + Wilson catalog corrections + occurrence rates + thermal emission + design-spec noise.
- **6 seasons: 1,990–2,940 HJs at > 5σ; 1,170–1,714 at > 10σ (phase curve AND eclipse).**
- G-dwarf hosts at 7–8 kpc — ×20 beyond current samples.
- One dataset validates the planets and measures their atmospheres.

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